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HOCKLEY SALT DOME, HARRIS COUNTY, TEXAS

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ABSTRACT

The Hockley salt dome in Harris County, Texas, is among the largest of the known salt domes of the Gulf Coast region. During the twenty-two years which have elapsed since it was discovered, nearly fifty wells have been drilled on and around it to depths ranging from 200 to 4,600 feet. Although numerous shows of oil, gas, and sulphur have been obtained from this exploration, there is today no commercial production of oil or sulphur from Hockley.

The authors point out that large areas of the cap rock are still untested and may possibly yield sulphur commercially in the future. While there is no prospect of commercial petroleum from the cap rock, there are large off-side areas which remain undrilled and offer some promise.

INTRODUCTION

LOCATION

Hockley salt dome is located in the northwestern portion of Harris County, Texas, 31 miles from Houston. The nearest railway station is the town of Hockley, on the main line of the Houston & Texas Central Railroad, $4\frac{3}{4}$ miles to the north. Katy, on the main line of the Missouri, Kansas & Texas Railroad, is 11 miles south of the dome.

The Hockley salt dome lies in the area where oil-producing domes predominate. It is situated, however, along the interior margin of this belt of productive domes, and at a greater distance from the coast (about 70 miles) than any other dome in this belt. Geologically, however, its position is no farther inland than the Humble or Davis Hill domes.

HISTORY

Attention was first directed to the indications which mark Hockley salt dome in 1905, four years after the discovery of Spindletop. To one Patillo Higgins credit for first recognition of these indications appears due. However, Lee, Napier, and Spears drilled in 1902 on the Theodore A. Sully Survey, entering a hard rock (probably sandstone) at 13 feet, and continuing in this to a depth of 60 feet. A small quantity of oil was found in the rock and a black shale was penetrated below the rock. Unlike most of the salt domes that, on the basis of topography, were recognized very shortly after the discovery of Spindletop, among them, Big Hill (Jefferson County), High Island, Barbers Hill, Damon Mound, West Columbia, Hoskins Mound, Bryan Heights, and Big Hill (Matagorda County), all of which are characterized by a pronounced local elevation at the surface, Hockley dome is not marked by a definite mound of this character. This probably accounts for the fact that it was not until four years after the finding of Spindletop that the rather prominent surface indications at Hockley were noticed.

Patillo Higgins had drilled at Spindletop before Lucas started operations there. After the Spindletop discovery he was the first to recognize the indications at Barbers Hill, High Island, the present Orange field, and a number of other domes. Visiting the Warren ranch in Harris County, Higgins realized the significance of surface indications of the Hockley dome and immediately negotiated a lease. In 1906 he began drilling operations, the first well being drilled to a depth of 730 feet, where cap rock was encountered, proving definitely the dome nature of this locality. Explorations were continued by Higgins during the years 1906, 1907, and 1908, when six wells were drilled, all of them encountering cap rock at a rather shallow depth. At that time dome development was confined to cap-rock exploration, because of the fact that the oil at Spindletop had been found in cap rock in the top of this dome. No thought was given to the possibility that oil might be present in lateral sands around the dome. All of the Higgins wells were therefore drilled within the cap-rock area, and while the first well encountered a small quantity of oil in some of the upper sands, no oil in commercial quantity was found during the period of the Higgins explorations.

Excepting one or two additional wells drilled to the cap rock, Hockley received no further attention until the year 1916, following the important discovery made at Sour Lake and Humble, in 1913, that oil in large volume existed not only in the cap rock, but likewise at deeper levels in lateral sands surrounding the domes. The Sour Lake and Humble development immediately focused attention again upon the considerable number of domes which had failed to yield production in the cap rock, and a new era of salt dome exploration was inaugurated.

In line with this development, the Texas Company, in 1916, acquired a new lease at Hockley, and in that year drilled a well to a depth of 3,100 feet. This

well encountered cap rock at 114 feet, and drilled into rock salt at 1,109 feet. The salt was said to be unusually pure, and was used by the drillers for table salt in camp. Due to a controversy concerning its leasehold rights, the Texas Company abandoned operations with the completion of this test, and the Gulf Production Company then secured a lease on the Coghill and Gulliver surveys, and began a period of very active exploration.

The Gulf Production Company's No. 1 Warren was completed in February, 1917, at a depth of 397 feet. This well was drilled into the cap rock and was very quickly abandoned. The drilling campaign of the Gulf Production Company extended from 1917 to 1922, inclusive, in which interval nineteen wells were drilled. None of these succeeded in establishing commercial production. All but five of the wells were drilled on the cap rock, and did very little except to define the limits of the dome. They were valueless as tests for oil.

In 1919 the Texas Exploration Company acquired leases on the west, northwest, and northeast sides of the Hockley dome, including practically all of the dome not covered by the Gulf Production Company's lease. The Texas Exploration Company has conducted a very active campaign of drilling since it began its first well in 1919, and this campaign is still in progress. In the five years that the company has been at work it has drilled a total of nineteen wells, and is now drilling its well No. 20. Of all these wells, however, only six have been off-side wells. The remainder have been drilled on the cap rock, in the effort either to establish some cap-rock production or to define the limits of this rock.

The fifth off-side test (Texas Exploration Company's No. 13 Warren) succeeded in finding an oil sand at 1,750 to 1,820 feet, and a small well with initial production of 25 barrels of 28-gravity oil was made in this sand.

The Texas Exploration Company's well No. 15, located 250 feet northeast of No. 13, was drilled to a depth of 2,090 feet, and was completed in February, 1924. It encountered the same oil sand as that found in No. 13, at a depth of 2,052 to 2,090 feet, and a 75-barrel well with oil of 22 gravity was completed in this sand.

Well No. 17 was drilled into anhydrite at 3,039 feet. It encountered highly saturated oil sands between 2,941 and 2,976 feet, but for some reason it was not an oil well.

In the entire twenty-two years of exploration at Hockley there have been drilled a total of forty-six wells, with one well drilling at the present time. Of these, thirty-two wells were either on the cap rock or were very shallow tests, less than 400 to 500 feet in depth. The remaining fourteen wells were off-side tests to depths ranging from 1,750 to 4,412 feet, and of these, two have succeeded in establishing a small quantity of production. It is worthy of note that there is still a very considerable part of the circumference of the dome untested, and in the untested portion there is still a possibility of producing oil. As indicated on the map (Fig. 5), the deep drilling has been confined to four spots around the periphery of the dome. These spots include the tests made by the Gulf Produc-

tion Company in wells No. 12 and No. 13, on the southeast side of the dome; the group of four wells of the Texas Exploration Company on the Houston Tap & Brazoria Railroad Company Survey No. 1, on the southwest side of the dome: the group of wells represented by Texas Exploration Company's wells No. 13, No. 15, and No. 17, on the northeast side of the dome; and the tests of the Gulf Production Company represented by wells No. 3, No. 6, and No. 15, on the east side of the dome.

All of the lateral area extending from Texas Exploration Company's well No. 10, on the southwest side, to its well No. 17, on the northeast side, representing fully one-half of the periphery, is still untested. There is likewise a gap of more than a mile between Texas Exploration Company's well No. 4 and Gulf Production Company's well No. 12. Likewise there is another gap on the southeast side of the dome, of more than a mile, between Gulf Production Company's well No. 13 and the same Company's well No. 3, still untested.

PHYSIOGRAPHY

Hockley salt dome is located at the interior margin of a seaward-facing terrace of the coastal plain of Texas, which the senior author has described in a recent paper[1] as the Alice Terrace. The outer and inner margins of this terrace are seaward-facing scarps, and the terrace is coterminous with the outcrop of the Lissie formation.

This terrace lies at a considerably higher elevation than the one immediately adjoining it to the south (described by the senior author as the Beaumont Terrace), and at a slightly less elevation than the terrace which lies immediately adjoining it to the north (Realitos Terrace).[2]

In Harris County the Alice Terrace is a very flat plain with dissection confined to the margins of the drainage channels. The soils of this terrace are mainly sand or sandy loams, and a considerable portion of this plain in Harris County is set with pine timber.

The scarp, which marks the interior margin of this terrace, is the most pronounced topographic feature in Harris County. It is plainly discernible to the eye, and can be traced by a line of low hills extending across the county in an east-west direction and passing into Montgomery County, about five miles north of Humble. It is very clearly defined on the topographic map, with one-foot contours, of Harris County, published by the U. S. Geol. Survey.

[1] Alexander Deussen, "Geology of Coastal Plain of Texas, West of Brazos River," *U. S. Geol. Survey Professional Paper 126* (1924), pp. 4–5.

[2] *Ibid.*

At the base of this scarp, in the vicinity of Hockley, the elevations average 170 feet. The high points on the crest of this scarp reach elevations as high as 200 feet, and an average height for this scarp of 30 feet above the lower plain may be safely assumed.

Hockley salt dome lies on this carp, its southeastern flank lying well within the limits of the Alice Terrace, and its northwestern flank extending across the scarp to the edge of the Realitos Terrace.

Because of its peculiar position with respect to this scarp, Hockley salt dome presents unusual topographic characteristics. Unlike many of the other domes, which are marked by distinct topographic mounds, Hockley dome is not characterized by a distinct surface mound, and it is only by a critical study of the topographic map that the influence of this salt intrusion can be recognized in the contours. A topographic map of the area in which Hockley dome is located is shown in Figure 1. An inspection of this map will show the influence of this intrusion in the local topography.

If the 170-foot contour be taken as typical, its normal course, when uninfluenced by the salt-dome intrusion, would be in a northeast and southwest direction, and it would normally extend directly across the Houston Tap & Brazoria Railroad Company Survey, from its northeast corner to its southwest corner. It will be noted, however, that instead of following this course, which is parallel to the present Gulf coast, at the northeast corner of the Houston Tap & Brazoria Railroad Company Survey this contour makes a sharp turn to the southeast, where it loops around a high area at the southeast corner of this survey. It then turns northwestward again near the center of the north line of this survey before resuming its normal course. There is an outlier of the 175-foot contour at the southeast corner of this survey, and this area of surface uplift is coincident with the southwestern margin of the dome. This is the only topographic influence discernible in connection with this salt-dome intrusion.

The disturbance of normal topography is evidently subsequent to the deposition of the Lissie formation, which underlies the Alice Terrace. Other well-known mounds of the Coastal Plain, such as Spindletop, Barbers Hill, Damon Mound, and Big Hill (Jefferson County), are without question of post-Beaumont age and it is rea-

sonable to assume that the Hockley disturbance is of about the same age, which would indicate that the movements at Hockley had continued well into the late Pleistocene.

The area above the salt core itself at Hockley is marked by a rather peculiar characteristic local topography. There are numerous pronounced small elevations, which have been described as pimples, and which occur at a number of places on the Coastal Plain. The surface of the land is locally very irregular and very rough. There are numerous depressions between these small elevations, and at a number of places vegetation does not grow, due to the presence of alkali and a small amount of salt in the soil. Near the southeast corner of the Houston Tap & Brazoria Railroad Company Survey, and at the point previously described as the one where the disturbance of the normal surface topography can be detected, there are, during periods of wet weather, gas seepages, and a post-hole auger in this area will uncover a small quantity of gas. In fact when Mr. Higgins first found this locality, he demonstrated the presence of gas in this vicinity by digging post holes and then igniting the gas. Likewise, in the soil in this immediate vicinity small flakes of sulphur can be detected, these being associated with the gas. Strong sulphur water which will blacken a coin in a few minutes and will leave a very large residue of mineral matter is present in the shallow wells, and is likewise a very characteristic feature in connection with the surface phenomena at Hockley dome.

SURFACE GEOLOGY

Actual exposures of the formations at Hockley are very scarce. At the northeastern margin of the dome, and near the southeast corner of the Robert Hall Survey, outcrops of red sand, which unquestionably can be referred to the Lafayette formation, are to be observed.

In the banks of Rock Hollow, which cuts across the Thomas Coghill Survey, extending south from the Warren ranchhouse and draining into Big Cypress Creek, are outcrops of a gray sandstone which can probably be referred to the Miocene or Lower Pliocene, and correlated with the Fleming. It would appear from this evidence that the formation above the cap rock at Hockley is the lower

Fleming. The junior author has made a microscopic examination of this material, and finds that it is indurated sulphurous yellow sandy

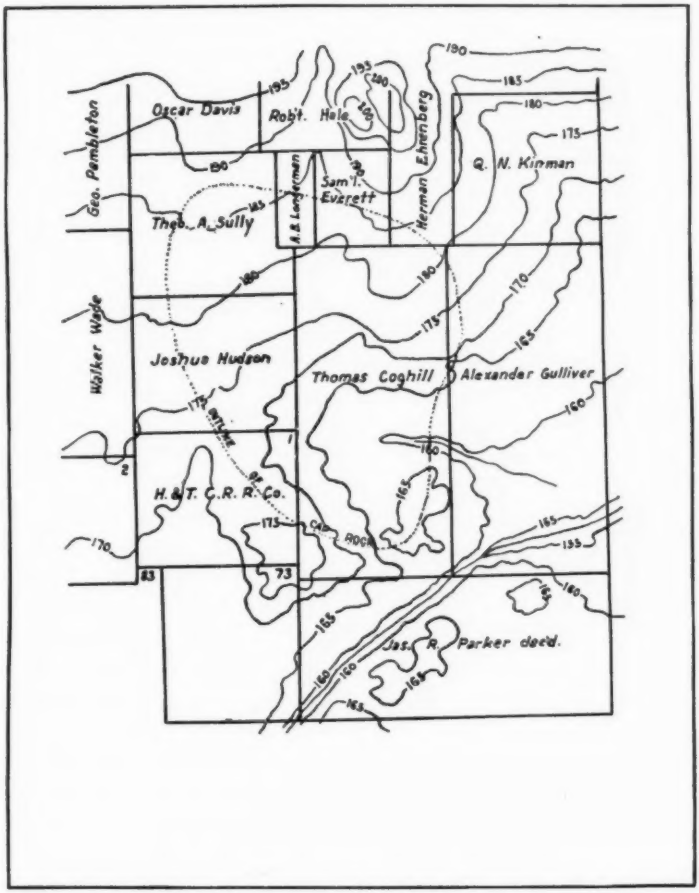


FIG. 1.—Map showing topography of Hockley Salt Dome in Harris County, Texas.

clay. When washed, the material leaves fragments of the clay and a small amount of blue sand. A sample from a nearby outcrop showed gray hard sandstone with a lime matrix. The material when washed

leaves fragments of the sandstone incrusted with clay and lime particles, and a residue of moderately coarse sand which constitutes 40 per cent. approximately, of the washed material.

Shark teeth, found in a bed of shale at 300 feet in Higgins well No. 1, were examined by Dr. L. Hussakof, of the American Museum of Natural History, New York, who reports:

> The shark teeth are identical with, or very close to, *Oxyrhina minuta* Agassiz, a Lower Miocene (Europe), and Upper Eocene (North Carolina) species. The other teeth represent the teleoston genus *Sphyraena*, which ranges from Eocene to modern times.

As it is highly improbable that Eocene beds were entered at a depth of 300 feet in this well, a Miocene (Fleming) horizon is indicated.[1]

The appearance of Fleming above the cap rock is distinct geologic evidence of uplift. This formation must have been intruded completely through the Lafayette, which in this vicinity is normally about 800 feet in thickness.

In the off-side wells immediately surrounding the area of the cap rock, the Lafayette is the surface formation, and is penetrated in the upper portion of these wells.

No dips in these surface formations can be detected which can be used to outline the limits of this dome.

SUBSURFACE GEOLOGY

Introduction.—A contour map showing the subsurface structure of Hockley salt dome is presented in Figure 2, and sections across the dome in Figures 3 and 4. These give an accurate picture of the geology of this dome.

It will be noted from the sections and map that Hockley is a typical Gulf Coast salt-dome structure. There is an intruded plug of rock salt capped by a typical cap rock composed of a sheet of anhydrite and an overlying sheet of limestone with the adjacent formations tilted against the sides. The outline of the dome is oval or egg-shaped, with the major axis trending in a direction N. 22° W., and the minor axis trending approximately N. 38° E.

[1] Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water Supply Paper 335* (1914), p. 76.

Salt core.—The salt core at Hockley rises to within 1,000 feet of the surface, and so far as our information extends, the top of the salt plug is fairly flat, as is shown on the cross-sections. The diam-

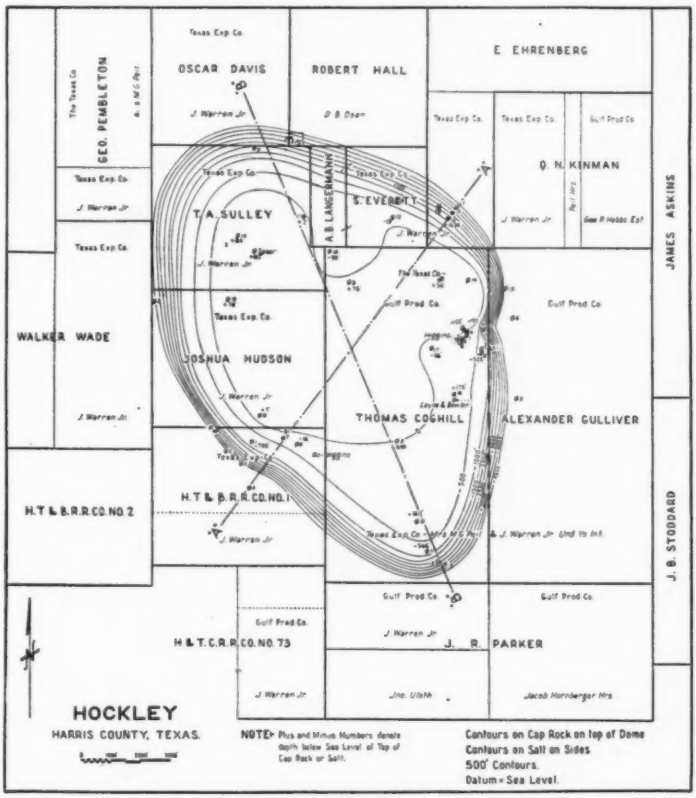

OSCAR DAVIS
ROBERT HALL
E. EHRENBERG
GEO. PEMBLETON
O. N. KINMAN
T. A. SULLEY
A. B. LANGERMANN
S. EVERETT
JAMES ASKINS
WALKER WADE
JOSHUA HUDSON
THOMAS COGHILL
ALEXANDER GULLIVER
J. B. STODDARD
H. T. & B. R. R. CO. NO. 2
H. T. & B. R. R. CO. NO. 1
H. & T. C. R. R. CO. NO. 73
J. R. PARKER
HOCKLEY
HARRIS COUNTY, TEXAS.
NOTE- Plus and Minus Numbers denote depth below Sea Level of Top of Cap Rock or Salt.
Contours on Cap Rock on top of Dome
Contours on Salt on Sides
500' Contours.
Datum = Sea Level

FIG. 2.—Subsurface contour of Hockley Salt Dome

eter of the core at the top of the salt from southwest to northeast, along section AA, is approximately 4 miles, or 21,000 feet, which is a distance considerably in excess of the average dome of the Gulf Coast.

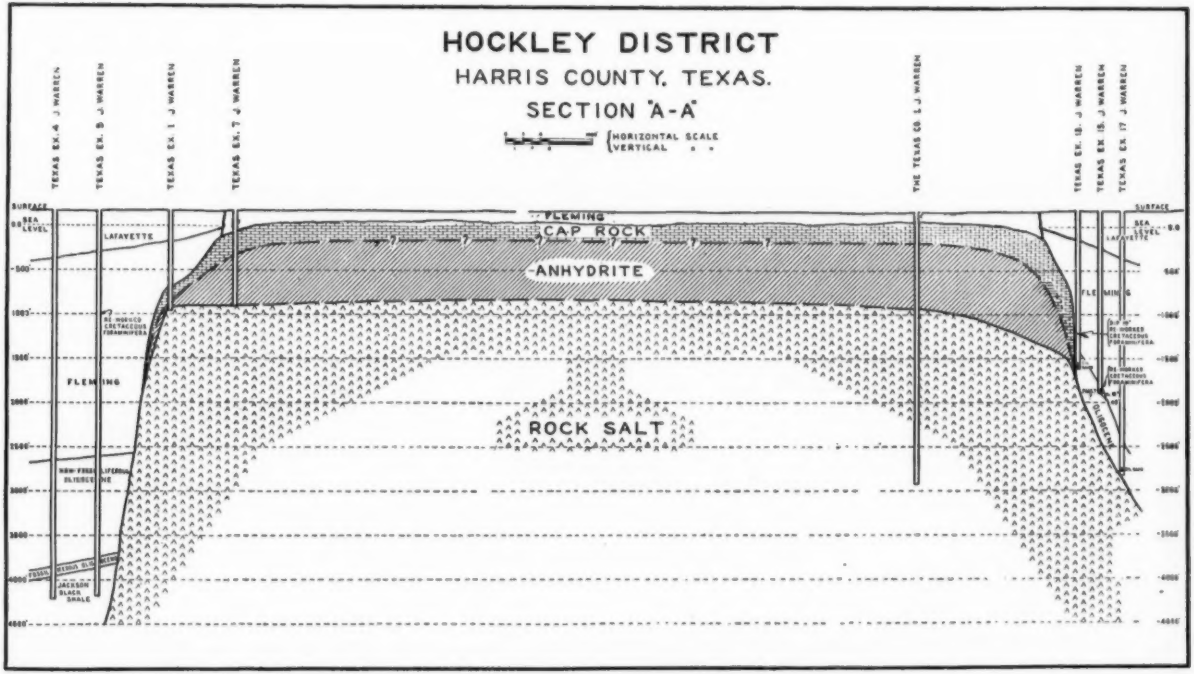


FIG. 3.—Section across Hockley Dome

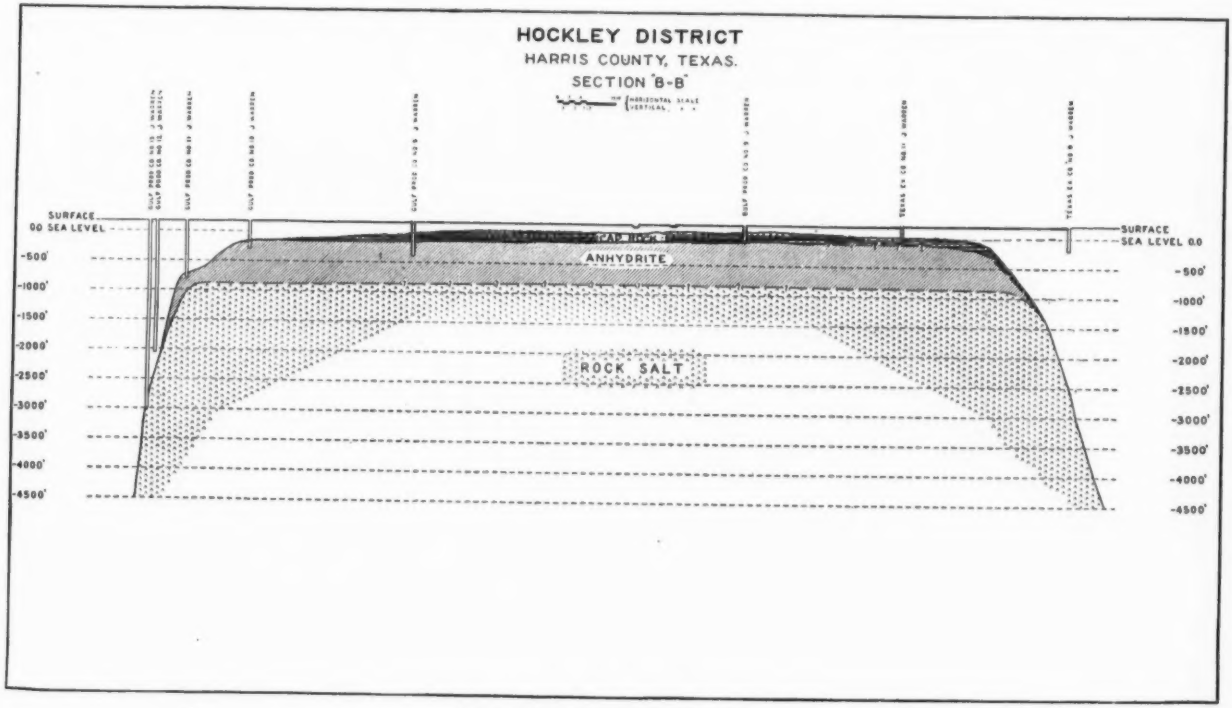


FIG. 4.—Section across Hockley Dome

The diameter of the salt plug in this same section at the 4,000-foot contour is approximately $4\frac{1}{4}$ miles, or 23,000 feet.

Along section BB, which extends from southeast to northwest, and in line with the major axis of this dome, the diameter of the salt core at the top and near the 1,000-foot contour is approximately 28,000 feet, or about 5.3 miles, which is also very considerably in excess of the diameter of the average dome. Only the Humble and Stratton Ridge domes approximate these dimensions. At the 4,000-foot contour in this section this dome is approximately 33,000 feet in width, or very nearly 6.2 miles.

So far as this structure has been explored, the sides of the salt core have very steep dips, the slope on the southeast side being approximately 2,500 feet in a horizontal distance of 1,750 feet, or at an angle of 55°. On the southwest side the salt surface dips approximately 3,500 feet in a horizontal distance of 1,500 feet, or at an angle of 67°. On the northeast side the dip of the salt surface is 2,000 feet in a horizontal distance of 1,000 feet, or at an angle of 60°. There is no information available as to the dip of the salt surface on the north or northwest flanks of this dome, as no wells have been drilled on these sides to date.

Cap.—The salt core at Hockley is overlain by a typical cap such as is found on most of the domes in the Gulf Coast district. This cap is composed of a sheet of porous cavernous limestone saturated with small quantities of oil and variable quantities of sulphur in places. The limestone sheet is approximately 450 feet in thickness over the greater part of the salt core.

Beneath the limestone sheet occurs a thick bed of dense, finely crystalline anhydrite, lying directly on the salt. This anhydrite is approximately 1,500 feet in thickness.

The cap forms a thimble over the salt, feathering out toward the edges, and extending down the sides of the salt core for a limited distance as a thin wedge of material. It is probable that in the lower limits of the dome there is no typical limestone cap between the salt and the normal sedimentary formations.

The contour of the top of the limestone cap rock is shown on the map (Fig. 5) by means of 50-foot contours. The highest contour passes near the northeast corner of the Houston Tap & Brazoria

Railroad Company Survey No. 1, the northeast corner of the Thomas Coghill Survey, and near the center of the T. A. Sulley Survey. The highest point on the cap rock, so far as known, oc-

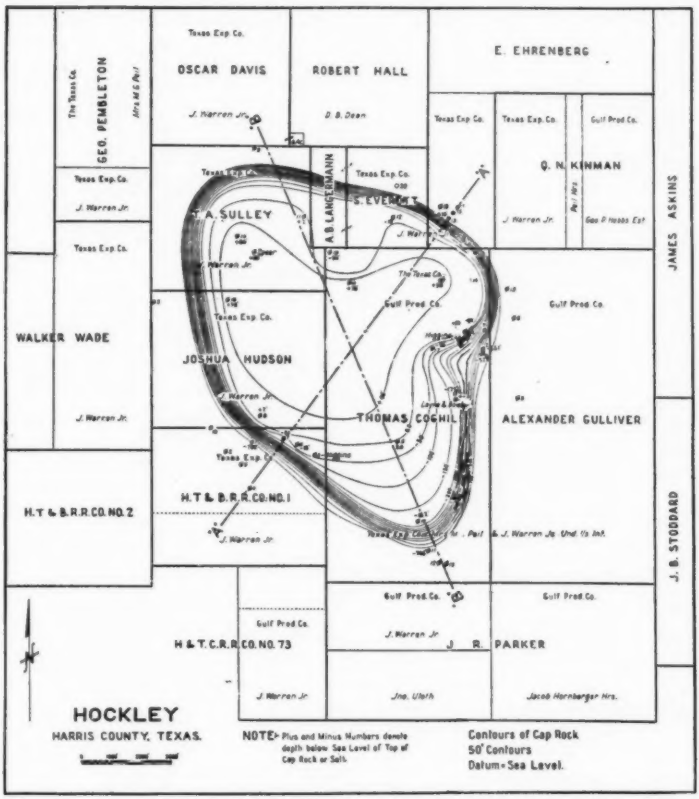


FIG. 5.—Map showing contour of the cap rock at Hockley

curs in the Spear well on the T. A. Sulley Survey, in the northwestern portion of the dome, where the top of the cap rock lies 85 feet above sea-level, or only 100 feet below the surface.

The sea-level contour includes the greater portion of the area of the cap rock. The 200-foot contour marks approximately the outer

limit of the cap rock, where it begins to dip steeply over the sides of the salt. Between the 200- and the 700-foot contours, the surface of the cap rock has a very steep dip, and if the overlying material were removed from this dome, these sides of the cap rock would appear as almost vertical cliffs 500 feet in height.

STRUCTURE OF SURROUNDING SEDIMENTS

Section AA gives a very good picture of the structure of the adjacent sediments. On the southwest side of the structure it appears, from the information available on the basis of drilled wells, that the formations are not very greatly tilted against the sides of the dome. It seems that the plug has cut through the formations at this point without dragging them very far vertically upward. The dip of the Oligocene on this side is approximately 500 feet in a horizontal distance of 2,000 feet, or at an angle of 10°. The Fleming and Lafayette formations appear to have about the same dip. On this side of the dome, what is hereafter called the non-fossiliferous Oligocene makes its appearance in well No. 5 of the Texas Exploration Company on the Warren lease, at approximately 2,625 feet below sea-level, and the fossiliferous Oligocene in this same well makes its appearance at approximately 3,750 feet below sea-level.

On the northeast side of the dome, as disclosed in wells No. 13, 15, and 17 of the Texas Exploration Company on the Warren lease, the dip of the adjacent formations seems to be considerably greater than is the case on the southwest side, and it is worth noting that in this particular area a small quantity of production has been found. On this side the top of the Fleming formation seems to have a dip of approximately 20°, and the top of the non-fossiliferous Oligocene has a dip of approximately 65°.

It appears that on this side of the dome the top of the non-fossiliferous Oligocene, as indicated in well No. 13 of the Texas Exploration Company, lies at a depth of approximately 1,400 feet below sea-level, and in well No. 17 of the Texas Exploration Company, at a depth of approximately 2,400 feet below sea-level. It is interesting to note that the top of the non-fossiliferous Oligocene makes its appearance on this side of the dome very nearly 1,000 feet

higher than on the southwest side, and it is likewise interesting to note that on this section of the dome, where the Oligocene beds have been dragged up much higher than on the southwest side, some production is obtained. It is probably true that a condition prerequisite to the occurrence of oil in the Gulf Coast salt domes is that the adjacent formations should be dragged up around the sides of the salt a considerable distance above their normal position.

STRATIGRAPHY

The normal sedimentary formations of the Hockley salt dome include the following:

Age	Formation
Pleistocene	Lissie
Late Pliocene	Lafayette
Pliocene / Miocene	Fleming
Oligocene	Oligocene
Eocene	Jackson

Lissie formation.—As previously mentioned, Hockley salt dome is located at the western margin of the outcrop of the Lissie formation. Owing to the uplift that has occurred in connection with this salt intrusion, there is no exposure of the Lissie in the immediate vicinity of the dome, and no materials of this formation are encountered in the wells drilled on top of this dome. Outcrops of the Lissie occur in a circumferential ring on the east, south, and southwest sides of the dome. The Lissie formation is made up of red sand and lenses of red gravelly clay. Beds of gravel are likewise very common.

In a spring in the vicinity of Gulf Production Company's wells No. 12 and No. 13, on the southeast side of the dome, there has recently been obtained an elephant tooth (third molar, upper left jaw, *Elephas imperator*) of early Pleistocene age.

Lafayette formation.—The cap-rock area at Hockley, with the exception of a thin veneer of recent material, is marked by the outcrop of an inlier of the Fleming formation. This inlier occurs, as previously indicated, at the normal contact line of the Lissie and Lafayette. Owing to the uplift of the Lafayette around the margins of this dome, a narrow loop of Lafayette material extends out from

the main area of the Lafayette surrounding the inlier of Fleming, on the east, south, and west sides. Beyond this loop of Lafayette on those sides outcrops of the Lissie appear.

The Lafayette directly overlies the Fleming clay on the sides of the dome. It does not overlie the Fleming in the cap-rock area.

As recorded by the drillers' logs, this formation at Hockley consists mainly of red sand, gravel, and bowlders. Beds of red gumbo and clay are likewise present. The presence of gravel and the predominating red clay of these beds readily distinguish them from the underlying Fleming.

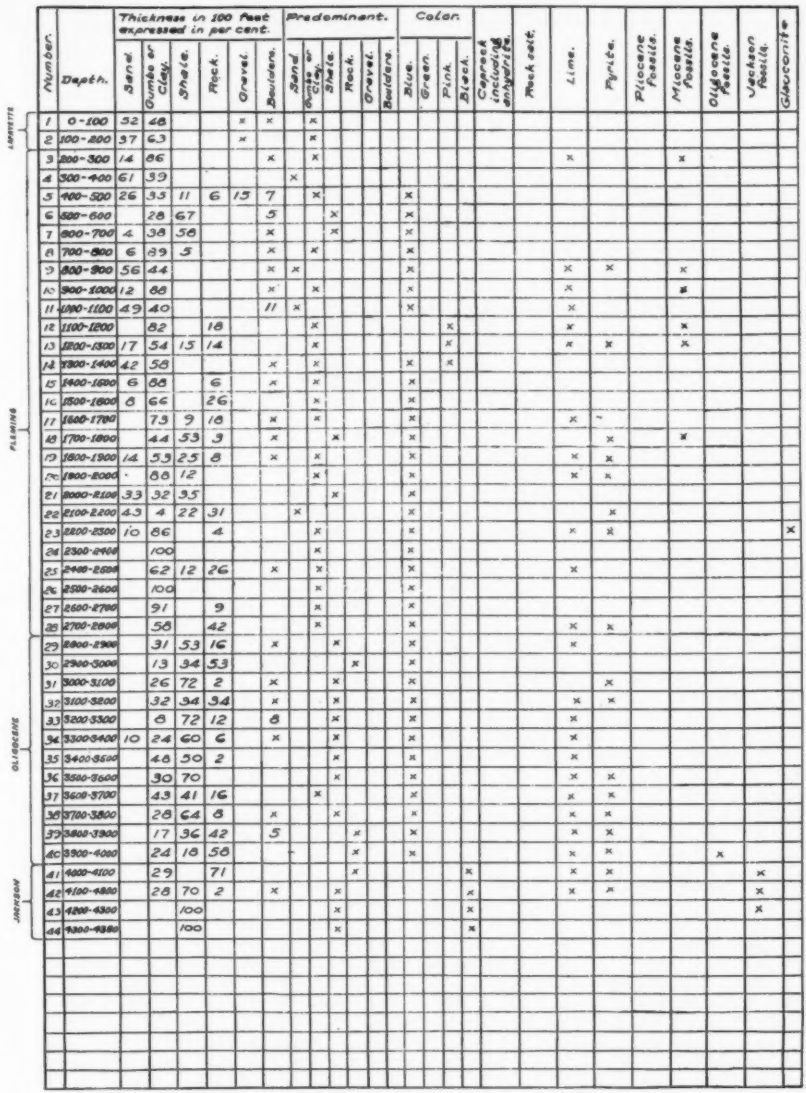
The accompanying chart (Fig. 6) of the diagnostic characters of the strata penetrated in Texas Exploration Company's well, John Warren No. 5, will readily show the difference in the constitution of the materials as compared with those of the underlying Fleming. Charts prepared for the various wells drilled on this dome, which are not reproduced here, show the same general characteristics for this formation.

No fossils are found in the Lafayette, which definitely fixes its age, but it is generally considered to be either very late Pliocene or very early Pleistocene.

In well No. 5 of the Texas Exploration Company on the Warren lease, this formation is approximately 400 feet in thickness. In well No. 4 on this same lease it is approximately 500 feet thick, and in well No. 17 it is approximately 800 feet thick.

Fleming formation.—The Fleming formation immediately underlies the Lafayette at Hockley, and overlies the Oligocene. As will be noted from the chart (Fig. 5), the formation consists mainly of blue calcareous gumbo. In the 2,600 feet of material representing the Fleming in Texas Exploration Company's No. 5 well on the Warren lease, blue calcareous gumbo is the predominating material. This is the case in seventeen 100-foot intervals as compared with nine 100-foot intervals which are composed of different materials. Out of the nine exceptional instances, three of these units are listed as pink calcareous gumbo, instead of blue calcareous gumbo; and two units are listed as blue shale. Only four of the 100-foot intervals in the total Fleming show a predominance of sand.

Pyrite in small quantities occurs in the sands of this formation,



Number.	Depth.	Thickness in 100 feet expressed in per cent.						Predominant.						Color.														
		Sand.	Gumbo or Clay.	Shale.	Rock.	Gravel.	Boulders.	Sand.	Gumbo or Clay.	Shale.	Rock.	Gravel.	Boulders.	Blue.	Green.	Pink.	Black.	Caprock including anhydrite.	Rock salt.	Lime.	Pyrite.	Pliocene fossils.	Miocene fossils.	Oligocene fossils.	Jackson fossils.	Glauconite.
1	0-100	32	48			x	x		x																	
2	100-200	37	63			x			x																	
3	200-300	14	86				x		x											x			x			
4	300-400	61	39					x																		
5	400-500	26	33	11	6	15	7		x					x													
6	500-600		28	67			5			x				x													
7	600-700	4	38	58			x			x				x													
8	700-800	6	89	5			x		x					x													
9	800-900	56	44				x	x						x						x	x		x				
10	900-1000	12	88				x		x					x						x			x				
11	1000-1100	49	40				11	x						x						x							
12	1100-1200		82		18				x							x				x			x				
13	1200-1300	17	54	15	14				x							x				x	x		x				
14	1300-1400	42	58				x		x					x		x											
15	1400-1500	6	88		6		x		x					x													
16	1500-1600	8	66		26				x					x													
17	1600-1700		73	9	18		x		x					x						x							
18	1700-1800		44	53	3		x			x				x							x		x				
19	1800-1900	14	59	25	8		x		x					x						x	x						
20	1900-2000		88	12					x					x						x	x						
21	2000-2100	33	32	35						x				x													
22	2100-2200	43	4	22	31			x						x							x						
23	2200-2300	10	86		4				x					x						x	x						x
24	2300-2400		100						x					x													
25	2400-2500		62	12	26		x		x					x						x							
26	2500-2600		100						x					x													
27	2600-2700		91		9				x					x													
28	2700-2800		58		42				x					x						x	x						
29	2800-2900		31	53	16		x			x				x						x							
30	2900-3000		13	34	53						x			x													
31	3000-3100		26	72	2		x			x				x							x						
32	3100-3200		32	34	34		x			x				x						x	x						
33	3200-3300		8	72	12		8			x				x						x							
34	3300-3400	10	24	60	6		x			x				x						x							
35	3400-3500		48	50	2					x				x						x							
36	3500-3600		30	70						x				x						x	x						
37	3600-3700		43	41	16				x					x						x	x						
38	3700-3800		28	64	8		x			x				x						x	x						
39	3800-3900		17	36	42		5				x			x						x	x						
40	3900-4000		24	18	58						x			x						x	x			x			
41	4000-4100		29		71						x						x			x	x					x	
42	4100-4200		28	70	2		x			x							x			x	x					x	
43	4200-4300			100						x							x									x	
44	4300-4380			100						x							x										

FIG. 6.—Chart of diagnostic character of strata penetrated in Texas Exploration Company well No. 5—John Warren at Hockley, Harris County, Texas, as determined from drillers log and samples.

and in the particular well previously referred to, No. 5, pyrite is recorded in eight of the 100-foot units. This pyrite is probably not indigenous to the formation, but is an accessory mineral related to dome intrusion.

There is one glauconite horizon recorded in well No. 5, in the 2,200–2,300-foot unit, and glauconite has been noted in other wells on this dome in the Fleming formation. For example, in well No. 10 of the Texas Exploration Company on the Warren lease, a glauconite horizon was encountered at 1,900 to 2,000 feet. It is also recorded at 1,400 to 1,500 feet in well No. 13 of the Texas Exploration Company on the Warren lease, in approximately the same relative stratigraphic position in the Fleming as in well No. 10. In this case, however, there are only some 1,100 feet of material represented by this formation, the lower portion of the Fleming not being present here. In well No. 15 of the Texas Exploration Company on the Warren lease, glauconite was recorded between 1,500 and 1,700 feet, which is probably the identical horizon as that in No. 13.

The Fleming formation is characterized by the presence of reworked Cretaceous Foraminifera. In the Hockley wells, these Foraminifera are confined to the Fleming formation, not being present in the overlying Lafayette or the underlying Oligocene. The species recognized in these wells include the following:

REWORKED CRETACEOUS FORAMINIFERA IN THE FLEMING FORMATION AT HOCKLEY

Trochammina inflata
Textularia sp.
Anomalina sp.
Globigerina sp.

In addition to these reworked Cretaceous fossils, the Fleming at Hockley contains fish teeth.

The maximum thickness of the Fleming recorded in the Hockley wells is 2,600 feet. This extreme thickness is exceptional, and suggests that Hockley dome is probably located near the base of some regional synclinal depression.

The Fleming formation includes materials of early Pliocene and of Miocene age, representing the equivalents of what the senior

author has described as the Oakville sandstone, the Lapara sands, and the Lagarto clays in the region west of Brazos River.[1]

The formation as encountered in these wells is identical in character with the formation as shown on the outcrop farther north, in Walker and adjoining counties.

Oligocene.—Beds referred to the Oligocene are encountered in the Hockley wells below the Fleming and above the Jackson formation.

As shown in the diagnostic chart (Fig. 5), the upper 1,000 feet of this unit consists predominantly of blue calcareous shale. In this part of the formation in the Texas Exploration Company's No. 5 Warren well, blue calcareous shale is recorded in six 100-foot intervals out of the ten 100-foot intervals represented. In one case blue rock is recorded and in another case blue gumbo.

In view of these facts, blue calcareous shale may be considered to be the characteristic material of the upper 1,000 feet of the Oligocene in the Hockley wells.

Pyrite was recorded in well No. 5 in nearly every sample examined from this formation, but, as in the case of the Fleming, this mineral is probably secondary, being related to the dome intrusion.

In well No. 5 of the Texas Exploration Company the lower 300 feet is recorded as rock, which is probably hard sandstone. The same is true with respect to the lower 200 feet of well No. 4 of the Texas Exploration Company, and it may be safely considered that the lower 200 or 300 feet of the Oligocene in the vicinity of Hockley dome is blue hard sandstone which may be correlated with the Vicksburg limestone of Louisiana and Mississippi. The upper blue shale series, approximately 1,000 feet in thickness, may be considered to be the equivalent of the Middle and Upper Oligocene, as shown on the outcrop by the Catahoula sandstone and the clays which Dumble has described as the Onalaska clays.[2]

The upper blue calcareous shale portion of the Oligocene in the Hockley wells contains no fossils, at least none of the cores recovered

[1] Alexander Deussen, "Geology of Coastal Plain of Texas, West of Brazos River," *U. S. Geol. Survey Professional Paper 126* (1924), pp. 97–102.

[2] E. T. Dumble, "The Geology of East Texas," *University of Texas Bulletin 1869* (1918), pp. 189–218.

from any of the wells have shown any fossils in this part of the formation.

The lower sandstone series has yielded a megascopic fauna, notably in wells No. 4 and No. 5 of the Texas Exploration Company. This fauna consists of the following species, identified by Mrs. Paul Applin, Dr. C. W. Cooke, and Dr. Julia Gardner.

OLIGOCENE FOSSILS FROM WELLS AT HOCKLEY

Arca sp. *Turritella* sp.	Identical with Vicksburgian sp.
Terebra sp. *Natica* sp. *Phos* sp.	Similar to Vicksburgian sp.
Nassa sp.	

No microscopic fauna has been found in the Oligocene in any of the Hockley wells.

The total thickness of the Oligocene, as shown in well No. 4 of the Texas Exploration Company, is 1,700 feet, of which the lower 200 feet consists of sandstone. This may be taken as representing the maximum thickness of this formation in the vicinity of the Hockley dome.

When taken in connection with the rather excessive thickness of the Fleming in this section, it is further evidence that Hockley dome is situated in a synclinal depression.

Jackson formation.—The lowest and oldest formation penetrated in any of the wells at Hockley is the Jackson. This is reached between 4,000 and 4,380 feet in the Texas Exploration Company's No. 5 Warren well, and between 4,200 and 4,412 feet in the No. 4 well. It immediately underlies the Oligocene.

The formation as recorded in these wells consists of black shale, and this is the characteristic black shale that commonly occurs immediately on top of, or adjacent to, the salt in many of the Gulf Coast salt domes.

In the only two wells which have reached this formation at Hockley, a very good collection of both megascopic and microscopic fossils has been obtained. The species include the following:

JACKSON FOSSILS FROM WELLS AT HOCKLEY

(Identified by Mrs. Paul Applin)

FORAMINIFERA

Ammobaculites sp., cf. to *foliaceous*
Textularia hockleyii
Textularia, probably var. of *sagittula*
Bolivina sp.
Nodosaria consorbrina, var. of *emaciata*
Cristellaria orbicularis
Cristellaria aculeata
Uvigerina pigmaea
Discorbis sp.
Truncatulina sp.
Pulvinulina sp.
Nonionina scapha
Nonionina sp.
Cornuspira, cf. *foliacea*
Quinqueloculina sp.
Triloculina oblonga

LARGE FOSSILS

Adeonellopsis teanoversa (Jackson and Claiborne)
Polyascosoecia sp.
Idmidronea rosacea
Venericardia sp.
Venericardia rotunda, young—broken (Eocene)
Corbula wailesiana (Jackson)
Phos sp. (close to Jackson sp.)
Volutilithes sp.
Volutilithes, probably *petrosus* fragment
Pleurotoma childreni, new var.
Turritella sp.
Terebrafusus (broken), close to *costatas*, but with more spiral ribs
Nassa sp., new
Triforia sp. (Jackson)
Eulima sp.
Dentalium, probably var. of *mississippiensis*
Cadulus sp.

The maximum thickness of the Jackson recorded in the Hockley wells is 250 feet. It is doubtful whether a complete section of this formation has been penetrated in any of these wells. The thicknesses

of various formations penetrated in the wells drilled at Hockley and a correlation of the sections shown by different wells are shown in Plate 18.

GEOLOGIC HISTORY OF THE DOME

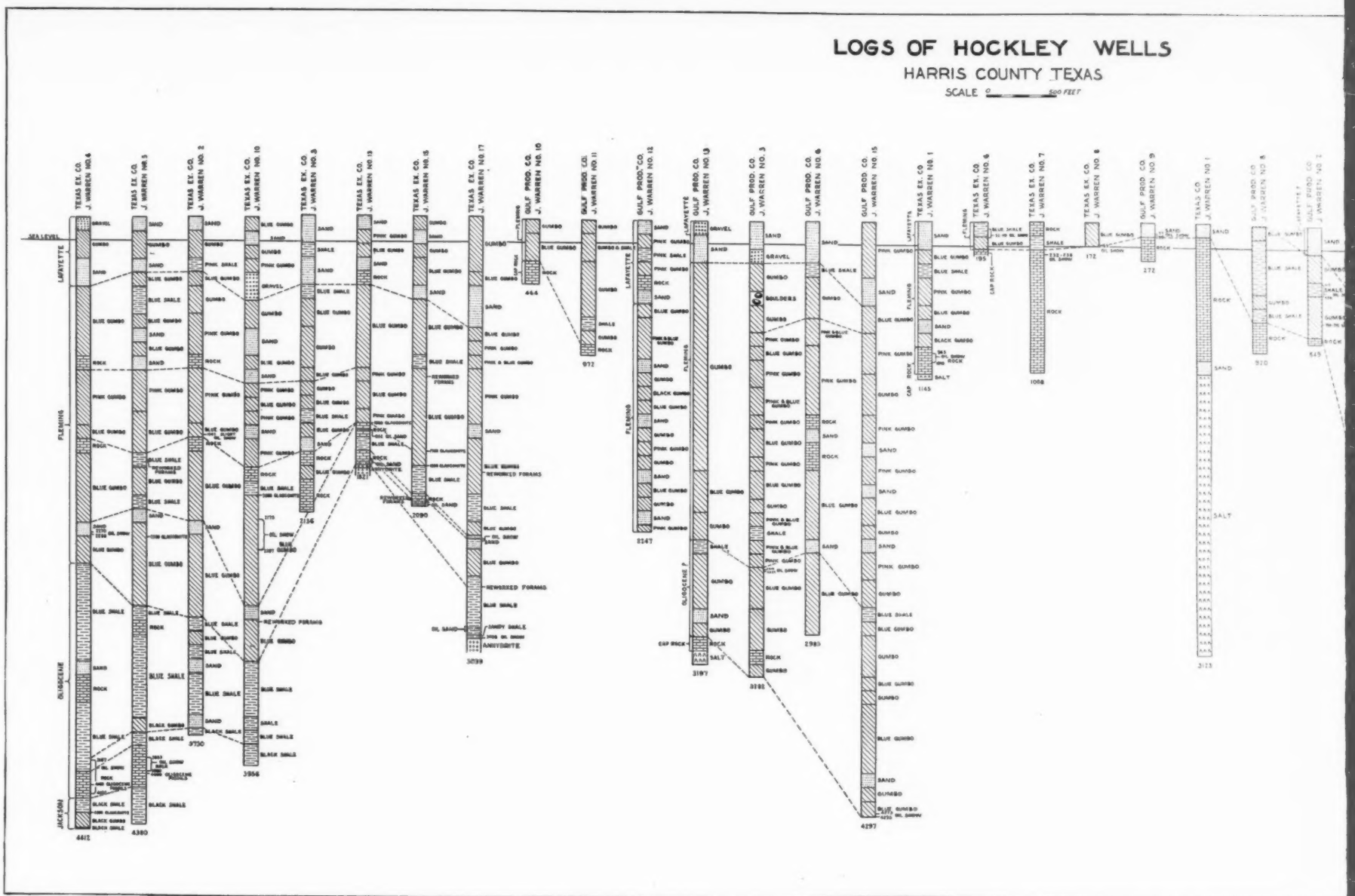
There is little direct geologic evidence indicating the time when the intrusion of the salt at Hockley began. That movements have continued on this dome as late as some time subsequent to the deposition of the Lafayette is clearly evidenced, and, as previously stated, it is probable that these movements have continued well into late Pleistocene or Beaumont time.

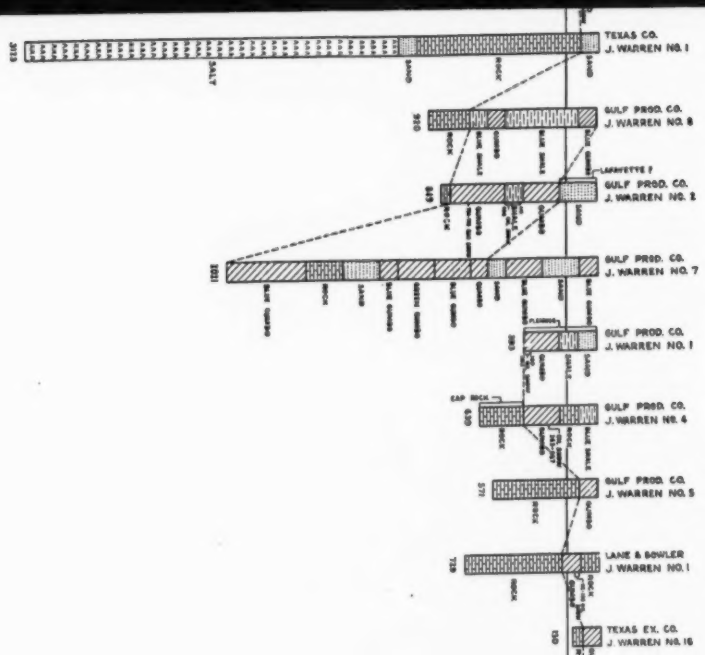
The Lafayette, Fleming, Oligocene, and Jackson show definite tilting against the sides of the dome, and this is notably true on the northeast side. That all of these formations have been tilted from their normal positions by the intrusion of the salt is perfectly plain. If the dome movement was active in Fleming time it must have been an island around which Fleming beds were being deposited. There is little evidence that the Fleming formation around the margin of the Hockley dome contains nearshore deposits, and in view of this fact it may well be that the intrusion of this salt was not initiated until the completion of the deposition of the Fleming, which would fix the age of the initial movement as late Pliocene or even very early Pleistocene.

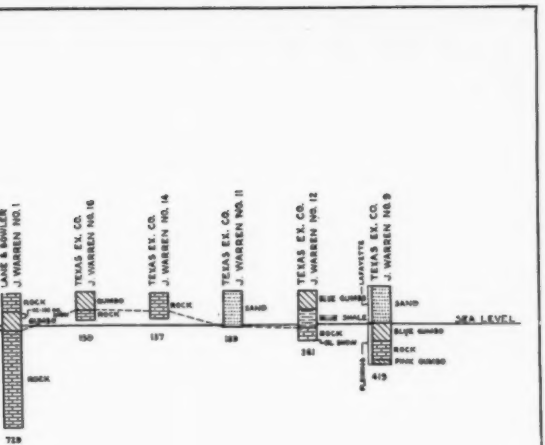
OIL AND GAS

As remarked in an earlier section of this paper, it was the oil encountered in a shallow well in 1902, and the seepages of gas, which resulted in the discovery of the salt core at Hockley. Notwithstanding the fact that explorations for oil on this dome have continued for a period of twenty-two years, very little in the way of actual oil production has been uncovered to date. All of the early explorations tested only the cap rock, and in a number of these wells a small quantity of oil was found, but nothing that could be considered commercial was discovered.

Texas Exploration Company's No. 1 John Warren well, on the cap rock, found showings of oil at 943 to 1,010 feet. Texas Exploration Company's No. 6 John Warren, on the cap rock, had showings of oil at 52 to 187 feet. Texas Exploration Company's No. 7 John Warren well, on the cap rock, had showings of oil from


LOGS OF HOCKLEY WELLS
HARRIS COUNTY TEXAS
SCALE 0 500 FEET
SEA LEVEL
LAFAYETTE
PLEISTOCENE
FLEMING
OLIGOCENE
JACKSON
TEXAS EX. CO. J. WARREN NO. 4
TEXAS EX. CO. J. WARREN NO. 3
TEXAS EX. CO. J. WARREN NO. 2
TEXAS EX. CO. J. WARREN NO. 10
TEXAS EX. CO. J. WARREN NO. 9
TEXAS EX. CO. J. WARREN NO. 13
TEXAS EX. CO. J. WARREN NO. 15
TEXAS EX. CO. J. WARREN NO. 17
GULF PROD. CO. J. WARREN NO. 10
GULF PROD. CO. J. WARREN NO. 11
GULF PROD. CO. J. WARREN NO. 12
GULF PROD. CO. J. WARREN NO. 13
GULF PROD. CO. J. WARREN NO. 3
GULF PROD. CO. J. WARREN NO. 6
GULF PROD. CO. J. WARREN NO. 15
TEXAS EX. CO. J. WARREN NO. 1
TEXAS EX. CO. J. WARREN NO. 4
TEXAS EX. CO. J. WARREN NO. 7
TEXAS EX. CO. J. WARREN NO. 8
GULF PROD. CO. J. WARREN NO. 5
TEXAS CO. J. WARREN NO. 1
GULF PROD. CO. J. WARREN NO. 8
GULF PROD. CO. J. WARREN NO. 2
4412
4380
3730
3956
3156
3090
3039
444
972
3147
3197
3185
2983
4297
195
1145
1088
172
272
3123
920
845


TEXAS CO.
J. WARREN NO. 1
GULF PROD. CO.
J. WARREN NO. 8
GULF PROD. CO.
J. WARREN NO. 2
GULF PROD. CO.
J. WARREN NO. 7
GULF PROD. CO.
J. WARREN NO. 1
GULF PROD. CO.
J. WARREN NO. 4
GULF PROD. CO.
J. WARREN NO. 5
LANE & BOWLER
J. WARREN NO. 1
TEXAS EX. CO.
J. WARREN NO. 16


LANE & BOWLER
J. WARREN NO. 1
ROCK
ROCK
729
TEXAS EX. CO.
J. WARREN NO. 10
GUMBO
ROCK
150
TEXAS EX. CO.
J. WARREN NO. 14
ROCK
137
TEXAS EX. CO.
J. WARREN NO. 11
SAND
189
TEXAS EX. CO.
J. WARREN NO. 12
BLUE GUMBO
BLUE SHALE
ROCK
361
LAFAYETTE
TEXAS EX. CO.
J. WARREN NO. 9
SAND
SEA LEVEL
BLUE GUMBO
ROCK
PINK GUMBO
419

232 to 238 feet. Texas Exploration Company's No. 8 John Warren found showings of oil in the top of the cap rock at 165 feet. Gulf Production Company's No. 2 Warren had showings of oil at intervals from 415 to 710 feet. Gulf Production Company's No. 4 Warren showed small quantities of oil at 263 to 267 feet, and at 365 feet had a gas blowout. Gulf Production Company's No. 9 Warren encountered showings of heavy oil from 77 to 90 feet.

Of the deep wells off-side, the following have had showings of oil: Texas Exploration Company's No. 2 John Warren made about two million feet of gas in a sand from 1,986 to 1,992 feet. From Texas Exploration Company's No. 4 Warren well, cores of oil-saturated sand were taken at 2,228 to 2,292 feet and at 3,912 to 3,933 feet, but this well when tested failed to yield production. Texas Exploration Company's No. 5 Warren well showed cores of oil-saturated sand at 3,883 to 3,913 feet and at 3,978 to 3,983 feet. In Texas Exploration Company's No. 10 well on the Warren lease no oil sands were found, but the gumbos between 2,175 and 2,644 feet were heavily saturated with oil. No sand was found in this interval which was capable of making production. Gulf Production Company's No. 3 Warren well reported a showing of oil at 2,519 to 2,527 feet. Gulf Production Company's No. 15 Warren well on the northeast side of the dome set 4-inch screen at 4,273 to 4,295 feet in a sand showing oil and gas. Pipe collapsed in this well and salt water broke in, ruining the well.

The most encouraging results thus far found in the off-side explorations at Hockley have been obtained in the Texas Exploration Company's wells No. 13 and No. 15 on the northeast side of the dome. No. 13 well on the Warren lease found a sand rock showing oil at 1,747 to 1,750 feet, a hard sand showing oil at 1,785 to 1,802 feet, and a sand with oil at 1,818 to 1,820 feet, immediately on top of the anhydrite. A 25-barrel well of 26-gravity oil was made in these sands. This well was completed on October 15, 1923, and is still pumping a few barrels of oil.

Texas Exploration Company's No. 15 Warren, completed on February 5, 1924, 250 feet northeast of No. 13, found the same series of oil sands encountered in No. 13 approximately 250 feet deeper. These sands were found in this well at 2,052 to 2,090 feet, and the

well when completed yielded 75 barrels of oil. Water soon broke in. While the well is still capable of yielding a small quantity of oil, production is of no great amount. The gravity of this oil is approximately 22 degrees, and the color is dark brown, as compared with the 26-gravity green oil in No. 13.

Texas Exploration Company's No. 17 Warren, located 250 feet northeast of No. 15, picked up showings of oil around 1,545 feet, and these showings continued at intervals to a depth of approximately 2,967 feet. Between 2,952 and 2,967 feet this well contained moderately coarse sand very heavily saturated with oil, but the well when tested failed to yield production.

The question is often asked as to whether Hockley will ever yield oil in commercial quantities, and as to whether this dome will enter the list of producing fields. Unfortunately, it is impossible to give a definite answer to these questions. It is argued by those who are doubtful of its possibilities that Hockley lies at the inner margin to the Gulf Coast salt-dome belt and is too far to the interior to be properly classed with the other oil-producing domes of the Gulf Coast. In other words, it is sometimes compared with the interior domes of northeast Texas in Anderson and Smith counties.

It is likewise contended by some that, owing to the fact that the Oligocene, or at least the upper portion of it, is of non-marine character, as evidenced by the absence of fossils, the chances are against obtaining production.

In answer to these arguments it can be stated that Hockley is identical in all respects with the structure of the other Gulf Coast salt domes, and has none of the features which characterize the interior domes. It has the typical cap rock and anhydrite of the other Gulf Coast salt domes, and in nearly all other respects is identical with the other producing domes. It is also no farther inland than Humble, which has yielded a greater quantity of production than any other Gulf Coast salt dome, and the geologic section penetrated by the Humble and Hockley domes is identical. However, at Humble all of the Oligocene is decidedly fossiliferous, which is not the case at Hockley.

The following may be considered adverse features of this dome from an oil-production standpoint. On the south, southeast, and southwest sides the salt appears to have penetrated the adjacent

formations without tilting them at very steep angles, and likewise it has not succeeded in dragging up with it any considerable portion of the lower-lying formations. In other words, the Oligocene and Jackson have not been dragged up very high against the sides of the salt on the south, southeast, and southwest sides, as has been the case at Humble, and as is the case where the domes yield production in great quantities. Further, the Fleming and Oligocene are abnormally thick in the immediate vicinity of the Hockley dome, indicating that this structure lies well within the bottom of some synclinal depression, and this may also possibly militate against its producing capacity.

On the other hand, it is to be recognized that on the northeast side the lower formations have apparently been dragged up very much higher than is the case on the southwest side, and it is likewise to be recognized that practically one-half of the perimeter of the dome extending from the Texas Exploration Company's well No. 15 on the northeast to Texas Exploration Company's well No. 10 on the southwest has not been tested with a deep well, and nothing is known concerning the structure of this portion of the dome.

The best evidence of the productive capacity of the Hockley dome is the production that has been obtained in off-side sands in wells No. 13 and No. 15, and it is axiomatic that where there is a small quantity of oil, future drilling generally reveals more. In nearly all of these deep off-side wells there is very considerable evidence of saturation. Likewise, small quantities of oil are present in the cap rock, unquestionably proving that there must be some accumulation around the sides, else these migrations into the cap rock would not occur.

The authors are therefore of the opinion that oil in commercial quantities will sooner or later be obtained at Hockley, and from evidence now at hand it appears that the most likely area extends northwest from the Texas Exploration Company's well No. 15, around the northern perimeter of this dome.

TABLE OF WELLS

In the attached table is given a complete list of wells drilled at Hockley to date, together with a summary of the facts pertaining to them.

TABLE I

WELLS ON HOCKLEY DOME, HARRIS COUNTY, TEXAS (AS OF AUGUST 26, 1924)

Name of Well	Date of Completion	Depth (Feet)	Depth of Oil Sand (Feet)	Initial Production (Barrels)	Present Production (Barrels)	Remarks
Layne and Bowler:						
John Warren No. 1	1907–8	729	.....	Dry	.....	Cap rock at 237 feet; anhydrite at 237 to 541 feet; sulphur at 220 to 237 feet and 354 to 504 feet; show of oil at 112 to 133 feet, 330 to 554 feet, and 504 to 541 feet. Elevation, 163 feet
Speed:						
John Warren No. 1	.....	.....	.....	Dry	.....	Much sulphur. Elevation, 163 feet
Spear:						
John Warren No. 1	.....	.....	.....	Dry	.....	Cap rock at approximately 100 feet (?). Elevation, 185 feet
The Texas Company:						
John Warren No. 1	7/5/16	3,100	.....	Dry	.....	Cap rock 114 to 1,109 feet; anhydrite at 231 to 258 feet; rock salt at 1,109 to 3,123 feet. Elevation, 173 feet. Salt, 98 per cent pure
Higgins:						
John Warren No. 1	1906	730	.....	Dry	.....	Sulphur water at 117 feet; sandy limestone at 14 to 730 feet, with a stratum of shale with Miocene shark teeth; limestone: 60.26 per cent SiO_2, 21.42 per cent CaO. Elevation, 163 feet
John Warren No. 2	1906	863	.....	Dry	.....	Salt at 750 feet; sulphur at 450 to 750 feet; fresh water at 312 feet; limy shale at 312 feet; hard sandy limestone at 550 to 863 feet; no water below 400 feet. Elevation, 163 feet

TABLE I—*Continued*

John Warren No. 3	1906	545	.....	Dry	.....	Water at 400 feet; limy shale at 312 feet; hard sandy limestone at 438 to 545 feet; no water below 400 feet. Elevation, 172 feet
John Warren No. 4	1907	510	.....	Dry	.....	Bowlders at 16 feet; hard sandy limestone at 400 feet. Elevation, 163 feet
John Warren No. 5	1907	370±	.....	Dry	.....	Hard sandy limestone at 400 feet
John Warren No. 6	1908	630	.....	Dry	.....	Bowlders in shale
Gulf Production Company:						
John Warren No. 1	2/23/17	397	.....	Dry	.....	Sulphur at 136 to 177 feet; oil shows at 360 to 372, 379 to 381, and 388 to 393 feet. Flowed oil and black sulphur water. Elevation, 163 feet
John Warren No. 2	4/28/17	849	.....	Dry	.....	Cap rock at 813 feet; anhydrite at 813 to 849 feet; show of oil at 415 to 433, 435 to 445, 447 to 451, and 496 to 498 feet; gas at 704 to 710 feet. Elevation, 162 feet
John Warren No. 3	10/18/17	3,282	.....	Dry	.....	Oil showing at 2,519 to 2,527 feet; gas at 1,501 to 1,505, 1,575 to 1,578, and 2,743 to 2,764 feet. Elevation, 163 feet
John Warren No. 4	1/19/18	639	.....	Dry	.....	Cap rock at 355 to 369 feet (lost returns); oil and gas at 263 to 267 feet; gas blowout at 365 feet. Elevation, 163 feet
John Warren No. 5	5/14/18	571	.....	Dry	.....	Cap rock at 163 feet; anhydrite at 330 to 571 feet. Elevation, 163 feet
John Warren No. 6	2/21/19	2,985	.....	Dry	.....	Elevation, 164 feet
John Warren No. 7	7/3/19	2,021	.....	Dry	.....	Elevation, 167 feet
John Warren No. 8	.....	920	.....	Dry	.....	Cap rock at 855 to 920 feet; anhydrite at 855 to 920 feet. Elevation, 164 feet
John Warren No. 9	3/10/20	272	.....	Dry	.....	Cap rock at 99 feet; anhydrite at 272 feet. Elevation, 175 feet. Show of heavy oil at 77 to 90 feet
John Warren No. 10	4/22/20	464	.....	Dry	.....	Cap rock at 327 feet; anhydrite at 327 to 464 feet. Elevation, 165 feet

TABLE I—*Continued*

Name of Well	Date of Completion	Depth (Feet)	Depth of Oil Sand (Feet)	Initial Production (Barrels)	Present Production (Barrels)	Remarks
Gulf Production Company:						
John Warren No. 11	6/26/20	974	.....	Dry	.....	Cap rock at 909 feet; anhydrite at 909 to 974 feet. Elevation, 163 feet
John Warren No. 12	11/16/20	2,247	.....	Dry	.....	Elevation, 163 feet
John Warren No. 13	.....	3,197	.....	Dry	.....	Rock salt at 3,197 feet. Elevation, 162 feet
John Warren No. 14	.....	567	.....	Dry	.....	Porous rock at 567 feet. Elevation, 170 feet
John Warren No. 15	?/?/22	4,302	.....	Dry	.....	Salt water at 4,302 feet; 4-inch screen set at 4,273 to 4,295 feet in formation showing oil and gas; pipe collapsed and salt water broke in. Elevation, 167 feet
John Warren No. 16	.....	800	.....	Dry	.....	Cap rock at 338 feet. Elevation, 163 feet
John Warren No. 17	.....	.....	.....	Dry	.....	Cap rock at 219 feet; anhydrite at 219 feet. Elevation, 163 feet
John Warren No. 18	.....	.....	.....	Dry	.....	Cap rock at 131 feet; rock salt at 1,059 feet. Elevation, 163 feet
John Warren No. 19	.....	.....	.....	Dry	.....	Cap rock at 265 feet; rock salt at 1,030 feet. Elevation, 175 feet
Texas Exploration Company:						
John Warren No. 1	2/17/20	1,145	.....	Dry	.....	Cap rock at 872 to 1,080 feet; anhydrite at 1,080 to 1,114 feet; rock salt at 1,114 to 1,145 feet; sulphur show at 942, 954, 1,010, 1,015, and 1,038 feet; oil show at 943, 954, 960, and 1,010 feet. Elevation, 172 feet
John Warren No. 2	1/18/21	3,750	.....	Dry	.....	Black shale at 3,711 to 3,750 feet; 2,000,000 feet gas at 1,986 to 1,992 feet. Elevation, 172 feet
John Warren No. 3	12/31/20	2,136	.....	Dry	.....	Sulphur trace at 1,690 feet. Elevation, 185 feet

TABLE I—*Continued*

John Warren No. 4	1/20/22	4,412	.....	Dry	.....	Black shale at 4,282 to 4,412 feet; oil show at 2,270, 2,288, 3,917, 3,923, 3,924, 3,930, and 4,162 feet. Elevation, 168 feet
John Warren No. 5	10/28/22	4,380	.....	Dry	.....	Black shale at 3,670 to 4,380 feet; oil show at 3,883 to 3,983 feet. Elevation, 171 feet
John Warren No. 6	6/22/22	195	.....	Dry	.....	Cap rock at 187 to 192 feet; black shale at 21 to 24 and 168 to 171 feet; sulphur water at 187 feet; oil show at 52, 110, 174, 178, and 187 feet. Elevation, 171 feet
John Warren No. 7	10/21/22	1,088	.....	Dry	.....	Cap rock at 252 feet; anhydrite at 252 to 1,080 feet; rock salt at 1,080 to 1,088 feet; oil show at 232 and 238 feet. Elevation, 171 feet
John Warren No. 8	11/8/22	172	.....	Dry	.....	Cap rock at 165 feet, with oil show. Elevation, 172 feet
John Warren No. 9	12/4/22	419	.....	Dry	.....	Elevation, 203 feet
John Warren No. 10	8/10/23	3,956	.....	Dry	.....	Oil show at 2,175 to 2,397 feet; good gas show at 2,584 feet. Elevation, 173 feet
John Warren No. 11		183	.....	Dry	.....	Cap rock at 183 feet. Elevation, 185 feet
John Warren No. 12	1/20/22 2/7/23	261	.....	Dry	.....	Cap rock at 186 feet; show of oil. Elevation, 180 feet
John Warren No. 13	10/15/23	1,821	1750–1820	25	.....	Anhydrite at 1,820 feet; oil sand at 1,552 feet. Elevation, 190 feet
John Warren No. 14	9/30/23	137	.....	Dry	.....	Cap rock at 101 feet; anhydrite at 135 feet. Elevation, 185 feet
John Warren No. 15	2/5/24	2,090	2052–2090	75	.....	Elevation, 187 feet
John Warren No. 16	1/29/24	150	.....	Dry	.....	Elevation, 187 feet
John Warren No. 17	8/25/24	3,039	2945–2976	Dry	.....	Anhydrite. Elevation, 186 feet
John Warren No. 18	?/?/24	600	.....	.....	.....	Elevation, 188 feet
John Warren No. 19	7/28/24	375	.....	.....	.....	Showing of oil at 136, 201, and 287 to 309 feet; anhydrite at 368 feet
John Warren No. 20	.....	.....	.....	.....	.....	Drilling at 400 feet on September 8, 1924

SULPHUR

The thick limestone cap at Hockley would appear to be favorable to the occurrence of sulphur. While a number of showings of sulphur have been obtained in various wells drilled at Hockley, it cannot be stated at this time that there is a commercial deposit of sulphur in the Hockley dome. Whatever sulphur is present is probably spotted, though considering the large area of this cap rock, it is possible that small tracts of 25–50 acres in extent may contain sulphur in sufficient quantities to justify exploitation.

The following wells have been reported as showing sulphur: Texas Exploration Company's No. 1 Warren has shown sulphur at 942 to 1,048 feet. Layne and Bowler's well No. 1 Warren encountered sulphur-bearing rock at 222 to 237 feet and at 354 to 504 feet. The so-called Speed well was reported to have shown much sulphur. Gulf Production Company's No. 1 Warren well encountered sulphur-bearing rock at 136 to 177 feet.

There is still a considerable portion of the cap rock untested for sulphur. As will be noted from map (Fig. 3), no well has penetrated this rock in the area outlined by the Spear well, Gulf Production Company's wells No. 9 and No. 17, Layne and Bowler's No. 1 Warren, Gulf Production Company's No. 5 Warren, and Texas Exploration Company's No. 7 Warren and No. 8 Warren. This area includes approximately 640 acres of land, and what might be developed in the way of sulphur by exploring this portion of the cap rock remains to be seen.

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SIGNIFICANCE OF SOME OF THE SURFACE STRUCTURES OF CENTRAL AND WESTERN KANSAS

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ABSTRACT

Surface structures of the Permian strata of Harvey and adjacent counties, of Cretaceous limestones of Russell and neighboring counties, and of the Smoky Hill chalk and Fort Hays limestone of Trego, Gove, Rooks and other counties are described and an interpretation in each case attempted. Those of the Harvey County region are referred to the solution of salt beds and the change of anhydrite to gypsum. These structures are thought to be confined to strata close to the surface. The surface structures of the Cretaceous strata are thought to be due to adjustments of these strata to the base on which they rest and to the irregularities of deposition within the strata themselves.

INTRODUCTION

Some ten years ago an examination was made of Harvey County from the point of view of oil possibilities. There were then discovered the deformed gypsum and associated strata which are such conspicuous features of some of the exposures. During the summer of 1924 parts of western Kansas were studied and the region of Harvey County revisited. It is the purpose of this article to describe some of the minor structural features which were observed in these regions and to attempt their interpretation. Thanks are due to Mr. B. C. LaDow for the opportunity of visiting parts of the region and to the Keys Petroleum Company for some subsurface data.

DESCRIPTION OF THE MINOR STRUCTURAL FEATURES

The structural features to which this article relates fall into three types of which each is probably due to a different cause although two of the types appear to be genetically related. The three types are: (1) the structures of the gypsum and associated strata of Harvey and adjacent counties; (2) the irregular anticlinal and domal structures of Russell and neighboring counties; (3) the faults and

steep dips in the Fort Hays limestone and Smoky Hill chalk of Gove, Trego, Graham, Sheridan, and Rooks counties.

THE STRUCTURE IN THE GYPSUM AND ASSOCIATED STRATA OF HARVEY AND ADJACENT COUNTIES

The structures in the gypsum and associated strata consist of minor crumplings of an order of magnitude of a few inches or less and anticlinal and domal structures which may attain 50 yards or so wide at the base and 20 or more feet high. The largest have been seen only in section. The strata in which these structures occur are of Permian age and consist of gypsum, thin white-and-gray limestones, and light-colored shales.

Both types of structure are splendidly exposed along some of the creeks over the eastern half of Harvey County. The minor crumplings are of little importance although their occasional occurrence in limited exposures in connection with the larger structures are known to have aided the reaching of extremely erroneous views on the part of some who have examined the region. The larger structures are of greater moment. They may be seen in cross-section in many exposures. One exposure may show the strata of one limb of an anticline while an adjacent exposure may show the corresponding limb of another anticline. A third exposure may show the opposite limb of a third anticline. Through projection of the various dips rather large structural features may be outlined. As tracing of horizons is essentially impossible, there are no reliable checks for the interpretations based on projection of dips. Experience with similar structures of like associations in other regions has led to the conclusion that these crumplings and foldings have no bearings upon the deeper and more fundamental structure of the region and that they arise from causes which are independent of those to which the latter are due.

It is believed that these structures are due to two causes. The smaller ones are thought to arise largely from the change of anhydrite to gypsum. It is known that calcium sulphate very commonly occurs as anhydrite—there are thick beds in the Russell County region—and hydrates to gypsum when it enters the sphere of meteoric ground-water circulation. The change to gypsum is attended by an increase in volume which may range from 30 to 50 per cent. It is thought that a change of this nature led to the minor

crumpling and perhaps some of the smaller anticlines. The larger arches are difficultly referred to the hydration of anhydrite. Westward these strata are under cover and some of them contain beds of salt. Such are not known to be present now in this region although their position falls within the strata which here are within the zone of ground-water circulation. It is considered that the salt beds were present here at one time and have been removed in solution in the ground water. There probably has also been some solution of gypsum. It is thought that the small anticlinal and domal structures and the corresponding synclinal structures arose as a consequence of the solution of the salt and gypsum strata.

THE IRREGULAR ANTICLINAL AND DOMAL STRUCTURES OF THE RUSSELL REGION

These structures have been seen in Russell, Lincoln, Barton, and Ellsworth counties, and they probably occur in other counties of the same general region. Two types of structure are shown in the surface strata: one with fairly definite trends and alignment and the other of irregular outlines. The former is exemplified by the Fairport anticline of western Russell County, and opinion is reserved as to the factors responsible for this type. The structure contours of the latter type wander around more or less in amoeboid fashion, and there are almost as many shapes in plan as there are shapes of that organism. They range in dimension from very small to some covering several sections. This type of structure is thought to extend not below the top of the Permian and to affect the strata of the Cretaceous only. Were the Cretaceous strata of this region oil producing, it is probable that this latter type of structure would have great possibilities for production. As the general conditions do not seem to be encouraging for production from the Cretaceous, it is considered that these structures deserve no consideration.

The Cretaceous rests unconformably on the Permian. The relief of this unconformity in western Kansas is not known, but as the entire Triassic and Jurassic are not present, the basal Cretaceous (Comanchean) begins with a sandstone and the unconformity has relief where exposed, it is assumed that similar conditions obtain in western Kansas.

The irregular structures are believed to have developed as a con-

sequence of deposition and settling of the Cretaceous sediments over irregularities of the Permian surface, or over and around sand lenses in the post-Permian sediments. Other geologists have also reached this conclusion.

CHALK STRUCTURES IN WESTERN KANSAS

Faults and steep dips occur in the Smoky Hill chalk and Fort Hays limestone of Trego, Gove, Sheridan, Rook, and Graham counties. These structural features were studied north of Quinter for about 20 miles along Solomon River, over a large area south of Quinter nearly to Smoky Hill River, and certain structures in the same general region which have been named the Penokee, Collyer-Quinter, Voda, Clayton, and Hackberry anticlines.

The displacement of the faults is not generally very great but it may reach 40 or more feet. The dips approximate $\frac{1}{2}°$ to 3°, but they may be as great as 10°. They show a considerable range in essentially every exposure. The exposures occur over occasional bad-land areas, along the streams and in the dry coulees. As a general proposition, the inclinations are extremely variable in direction in most exposures, and it was found impossible in many exposures, particularly the larger ones, to select any inclination as the dominant one. Dip in a single direction may prevail in small exposures. On steep slopes it was observed that the blocks very commonly incline into the slopes.

Maps have been made of the structures which have been named, the construction being based on the projection of dips to a point of convergence. Structural contours were drawn around the inferred anticlines thus outlined. In order to produce convergence it seems that it must have been necessary to assume in each exposure that certain inclinations were the dominant ones and to disregard the others. Were this not done it does not seem possible that anything resembling convergence could have been produced. It is not known what were the criteria used in selecting the dominant dips.

It is known that at least nine inferred anticlinal structures have been mapped through projection and convergence of dips. Others are known to have been mapped, but on what data is not known. Maps which have been published[1] are those of the Hell Creek struc-

[1] C. T. Lupton, W. Lee, and Van Burgh, "Oil Possibilities of Western Kansas," *Bull. Amer. Assoc. Pet. Geologists*, Vol. 6 (1922), pp. 69–90.

ture in Gove, Logan, and Scott counties; the Alanthus structure in Logan County; the Chalk Creek dome in Logan and Scott counties, and the Twin Buttes anticline in Logan County. Commercial maps on the same basis have been made of the Clayton structure in Graham County, the Hackberry structure in Gove County, the Penokee structure in Graham County, and the Voda structure in Trego County. Another inferred structure which has been mapped is that known as the Collyer-Quinter in Sheridan, Graham, and Trego counties. This is said to have been mapped with plane table and alidade, using the "red chalk of the Niobrara" as a horizon. I have seen and studied the Penokee, Hackberry, Voda, Clayton, Collyer-Quinter, and the north end of the Alanthus structures. I spent two days going over the Collyer-Quinter structure, giving careful attention to the dips and the key horizon. The variety of inclinations shown in most of the exposures led to the conclusion that very little reliance can be placed on them as criteria of subsurface structure. A study of the "red chalk" led to the further conclusion that it probably is related to the base of the Tertiary and the ground-water level and that it transgresses from bed to bed and hence has no bearing whatever on the nature of the structure. Drilling on the Collyer-Quinter structure has led to its abandonment.

The Penokee structure centers about the village of Penokee in Graham County and has an inferred closure of 75 feet. The structure has been core drilled to the top of the Fort Hays limestone, five wells having been drilled, three a mile apart north and south and one east and one west of the middle of the three. The western well is a mile from the middle one, and the eastern is a half-mile from that of the middle. The central well of the five is on the southeast side of the inferred apex as mapped from projection of dips. These test wells showed a drop in the beds of 11 feet to the east, 5 feet to the south, 21 feet to the west, and a rise of 2 feet to the north. The map based on dips showed for the distances of the wells a drop of 50 feet to the east, 50 feet to the south, 25 feet to the west, and about 35 feet to the north. These figures rather strongly suggest that the dips of the chalk bear little relation to the structure so far as such is indicated by the top of the Fort Hays limestone.

The Clayton structure in T. 7, 8, and 9 S., R. 20 and 21 W., in

Graham and Rooks counties has a total inferred closure based on dips of 75 feet, the inferred form being an anticline with its axis in a north-south direction. This structure has also been core drilled to the top of the Fort Hays limestone. The wells show a drop to the east of 47 feet in a distance of nearly 2 miles, 42 feet to the south in a distance of a little over a mile, following which the top of the limestone rises southward 33 feet in the next mile and a half where the map prepared from the dips indicates that the structure falls for that distance and beyond for an additional 2 miles. Westward the top of the Fort Hays drops 25 feet in the first half-mile, following which it rises westward, while northward it drops 35 feet in 2 miles. The map based on the projected dips gives for the same distances a drop of 100 feet to the east, 40–50 feet drop to the south with a continued fall in that direction, 50 feet to the west, and 50 feet to the north. Here again it appears that projection of dips leads to extremely erroneous results.

The Hackberry structure in T. 13 and 14 S., R. 25–27 W., in Gove and Trego counties was being core drilled at the time studied. The results have not been learned. However, the entire structure was examined rather carefully together with a considerable area to the south and east. The result of this examination suggested that some half-dozen structures might be outlined by as many individuals over the general region of the Hackberry structure.

The Voda structure was also carefully examined with very similar results although there appears to be a greater consistency of dips in the various exposures. This consistency, however, loses value because of the large areas of no exposure.

Other areas have been studied where it is not known that any structures have been outlined, and these areas show similar relationships to those where structures have been mapped, and the selection of certain dips considered dominant would permit anticlines to be outlined.

The facts derived from the study of the chalk structures of western Kansas show as follows: that platting of structure based on dips leads to incorrect results so far as the structure may be considered to be shown by the top of the Fort Hays limestone; that projection of dips in some places shows a structure the direct oppo-

site of that indicated by the top of the Fort Hays limestone; that the dips in any exposure are usually variable in inclination and direction; and that in many instances the obvious dipping of blocks into the slopes suggests that their positions are related to surficial slumping. In general, it is believed rather definitely that the more or less steep dips shown in the chalk beds are in most instances not indicative of deep, subsurface structure and that most of these inclinations will disappear in underlying shales.

So far it has been more or less assumed that the top of the Fort Hays limestone might reflect the deep, subsurface structure. It is now desired to question this assumption. It is thought probable that the position of the Fort Hays limestone has been determined by the same causes which are held responsible for the manifold variety of dips which are so patent in the Smoky Hill chalk. Also, it seems probable that some of the structures of the Fort Hays limestones are of the same character as the irregularly shaped anticlines of the Russell region and should be referred to the same origin.

As necessary information for explaining the great variety of inclinations in the Smoky Hill chalk an appreciation of the geologic section to the top of the Permian is essential. This is best obtained by giving the section which was worked out from the study of the cuttings of the Voda well.

RECORD OF THE VODA WELL, TREGO COUNTY, KANSAS

	Feet
Soil	25
Tertiary:	
Mortar beds: pebbles and rock fragments of various kinds cemented by calcium carbonate	7
Blue and yellow shale	38
Smoky Hill chalk: soft chalk, yellow on exposure	290
Fort Hays limestone: white chalk, soft and brittle	50
Carlile shale: soft, blue shale	250
Greenhorn limestone (Post-Rock and Flagstone horizons): interbedded soft, chalky limestone and blue shale	65
Graneros shale: soft, blue and dark shale	85
Dakota: interbedded sandstone and shales of red, blue, and dark colors	265
Comanchean: dark-blue and black shale underlaid by white quartz sandstone	260
Permian redbeds	

The surface on the Permian was developed by erosion, and hence it is probably irregular. The sandstone at the base of the Comanchean appears to be lenticular, and the same is true of the sands of the Dakota. In the section are the thick Carlile shale formation, the somewhat thinner Graneros shale, and various shale units in the Dakota. Not one of these units has any competency, and they would certainly yield to any irregularities of underlying material. The chalk and limestone members are extremely weak and brittle and would break into small blocks in adjustment to movement of the underlying shales. The breaking and tilting of blocks would be the greater the more extensive the shales beneath. The various shale members would have adjusted themselves to the materials upon which they rest whether these be Permian hills or sand lenses in the Comanchean or Dakota. The chalks would then have tilted in response to the movement of the shales. A factor which certainly accounts for some of the inclined blocks is surficial faulting or slumping. Particularly is this the probable explanation of those dipping into the slopes. Another possible cause of the tilting of the chalk blocks is adjustment to solution cavities within itself. The faults and joints in the chalk are frequently filled with pure calcite. There is a possibilty that this came from below, giving rise to caves into which the overlying blocks settled. However, it seems more probable that settling in response to adjustments of the shale is the major cause of the tilting.

Regional movement would be very largely adjusted in the shales, but it is thought that the adjustments would be in a broad way and that the effects in the chalk would be of a similar nature. It is not intended to suggest that structures due to crustal deformation are not present.

Basing conclusions on the areas studied, it is not believed to be possible to outline the local structures of the chalk beds of western Kansas by means of the inclinations shown in these strata. These are believed to be adjustments to movements of the underlying shales, which in turn are adjusted to irregularities of the Permian floor or the presence of sand lenses in the Cretaceous. It is not believed that surface structures are likely to extend to the base of the

Cretaceous strata. While some of them may do so, it is not known that there are criteria by which such may be differentiated.

If the Hell Creek, Alanthus, Elkader, Chalk Creek, Twin Butte, and any other structures of the chalk of western Kansas have been based on structural features similar to those of the Penokee and other structures studied, I am of the opinion that there is little more chance of their actual existence than I consider to be the case for those studied.

DISCUSSION

W. W. RUBEY: Dr. Twenhofel has attributed the origin of the faults and locally steep dips in the Niobrara outcrops in western Kansas to slumping of these rocks over the 200 feet of clay beds in the Carlile shale. Although perhaps less common than in the Niobrara formation, faults with calcite veins and associated with steep dips occur in the lower part of the Carlile shale (below the thick clay-shale portion) in Ellis County, and similar structural features are reported in the Greenhorn limestone. The underlying Graneros shale, which is but 40 feet thick, seems less likely to cause this type of structure but the similarity of the faults in the Niobrara to those in the lower chalk beds suggests that they may possibly have been formed by the same process, whatever that may have been.

I should like to ask Dr. Twenhofel: (1) whether or not he was able to detect any systematic arrangement or orientation of these faults in the Niobrara formation, and (2) whether he has any information other than that of probability for attributing the origin of his amoeboid folds to consolidation over a post-Permian unconformity rather than over an older unconformity. The demonstrated presence in Missouri, eastern Kansas, and northeastern Oklahoma of a post-Mississippian unconformity, with hills and valleys in hard rocks, leads one to suspect a similar condition in central Kansas.

G. E. EBMEYER: If structures other than the Fairport anticline are not reflected at depths below the Permian, how do you account for the excellent showings of oil in other structures in that vicinity—some as much as 30 miles distant from foregoing structure?

R. C. CONKLING: At Estellind, Hall County, Texas, the dolomite layers dip from the top of the structure for 5 or 6 inches to Pease River at the rate of 35–40 feet per mile. The dip to the north to the Prairie Dog fork of Red River was shorter but steeper. When the structure was drilled there was found to be no subsurface structure below 2,500–3,000 feet. I consider this large structure entirely due to solution.

J. B. UMPLEBY: Bearing on the question by Dr. Bloesch, it may be of interest that we found 68 feet of gypsum in the section of Hall County, Texas. The measurement is based on five wells and numerous surface exposures.

J. S. IRWIN: I should like to ask Dr. Twenhofel if he has noted any general tendency for areas of high structure, as determined on the Greenhorn and Fort Hays limestones, to occupy topographic divides while areas of low structure occupy major drainage lines? Such a more-or-less definite relationship of structure to topography and drainage I have noted in a number of instances, suggesting solution in a large way by subsurface drainage as an underlying cause of the structural configuration in the Benton and Niobrara of western Kansas.

W. H. TWENHOFEL: There may be some relation between the apparent structural highs of western Kansas, as mapped on the Fort Hays limestones and as determined from dips of the Smoky Hill chalk, and the topographic highs. Such obtains about the Voda structure, but I have been unable to see such a relationship in the others studied and in some of them, as the Penokee, the opposite is the case. I consider structures mapped on the Greenhorn limestone as due to settling over the various materials beneath, or actual deformation.

With respect to the fractures and faults of the areas studied, I have been able to reach no positive conclusions. I have found much divergence of trend and I have been unable to distinguish those which probably do not extend to any great depths from others which possibly may extend long distances downward. In my judgment the majority of these faults and fractures do not extend to the top of the Permian.

CALCIUM CHLORIDE WATERS FROM CERTAIN OIL FIELDS IN VENTURA COUNTY, CALIFORNIA

F. S. HUDSON AND N. L. TALIAFERRO

ABSTRACT

While engaged in a detailed study of the South Mountain and Shiells' Canyon oil fields it was found that the chemical composition of the underground waters differs considerably from that of the usual California oil-field brines, in that calcium chloride, instead of sodium chloride, is the chief constituent. The fact that this difference in composition persists in the fields along the south side of Santa Clara River indicates that these underground waters had a different origin, or a somewhat different subsequent history, from the waters in other fields, both in Ventura County and other parts of the state. Although calcium chloride waters occur in other parts of the world they are far from a common type of oil-field brine, and they therefore seem to owe their origin to certain special conditions.

The purpose of the present paper is to give a brief account of the occurrence and character of these waters and to suggest their probable origin.

OCCURRENCE OF THE WATERS

The calcium chloride waters under consideration are confined to the Sespe formation, which contains the oil-bearing horizons in the fields along the south side of Santa Clara River, in Ventura County, California. The stratigraphy and structure of this region is so well known that only a brief résumé will be given.

The Oak Ridge–South Mountain range is an important topographic feature which extends in an east-west direction through south central Ventura County; the structure of this ridge is essentially anticlinal, although the topographic and structural crests do not coincide. The crest of the Oak Ridge–South Mountain anticline lies along the northern front of the range, a short distance south of the edge of Santa Clara Valley. This uplift is a long, almost unbroken anticline along which occur several strongly defined domes, separated by structural sags. The Sespe formation is exposed at the surface in the domes, the saddles usually being occupied by the Vaqueros formation and, in the deeper sags, by Monterey shale. The crest of the ridge, which is on the south flank of the uplift, is

usually underlain by Monterey shale. The northern flank of the anticline is paralleled by a high-angle thrust fault which is usually obscured by valley alluvium but which is here and there visible along the northern edge of the range.

The Sespe formation consists of a thick series of red, yellow, and white sandstones, red, maroon, gray, and green sandy shales, sticky red and maroon clays, and numerous lenses of conglomerate. The rapid lateral variation, the general character of the beds, the absence of marine fossils, and the presence of land vertebrates in the upper part, clearly indicate that the Sespe is a land-laid series. Relatively thin lacustrine deposits occasionally occur, indicating that there were small lakes in the basin in which the Sespe was deposited. These lake deposits consist of very pure, sticky, finely banded maroon and white clays, with a few thin layers of slightly salty white clay. The total thickness of the Sespe, along the Oak Ridge–South Mountain uplift, is unknown. The greatest exposed thickness in this region, 1,700 to 1,800 feet, is in the South Mountain oil field; wells in this field have penetrated over 4,000 feet of additional beds without having passed through the Sespe, so its thickness must be at least 6,000 feet.

Meager vertebrate remains are the only fossils that have been found. In the South Mountain field, 800 to 1,000 feet below the top of the series, two small jaws were found which have been identified by Dr. Chester Stock, of the department of paleontology of the University of California, as belonging to the genus *Hypertragulus* (primitive antelope), indicating an Upper Oligocene or Lower Miocene age.

The character of the sediments and of the included fossils indicate that this series of red beds was deposited on land under somewhat arid conditions. However, extreme desert conditions are not thought to have existed, as there are no signs of salt deposits, nor do the underground waters approach bitterns in concentration or composition.

Igneous intrusions are not numerous in the Sespe but they occur occasionally, the most notable examples being a dacite dike on the northern flank of the South Mountain dome, the thick dacite sill between the Sespe and Vaqueros, on the southern flank of the same

dome, and a very small intrusion of mica hornblende andesite about one mile west of the South Mountain field. No other intrusions are known to occur along the Oak Ridge–South Mountain uplift.

The waters which form the subject of this paper occur in wells in the South Mountain and Shiells' Canyon oil fields and in the unproductive Wiley Canyon dome, at depths ranging from 600 feet to nearly 5,000 feet below the surface. As all the wells in this region are drilled with cable tools, it is possible to obtain representative water samples with a minimum amount of dilution by surface or drilling water. In the South Mountain oil field very little salt water is encountered between the upper water and bottom water at about 3,500 feet (on the crest). Comparatively little water is produced with the oil in this field. A fairly large amount of water is pumped with the oil from the old shallow wells in the Shiells' Canyon field. Although no large flows of salt water have been encountered in the South Mountain or Shiells' Canyon oil fields, a well drilled on the barren Wiley Canyon dome encountered strong flows of salt water at several horizons. The deepest waters encountered were warm, but not excessively so; the maximum temperature recorded was 104° F. in water at a depth of 4,970 feet in the Wiley Canyon well.

The salt waters encountered in the South Mountain and Shiells' Canyon fields are rather intimately associated with oil, but in the Wiley Canyon dome, which is barren of oil, identical waters occur. For this reason it seems certain that the character of the waters is not due to reaction with oil.

CHARACTER OF THE WATERS

The chemical character of the waters from the Sespe formation, from localities along the Oak Ridge–South Mountain uplift, is shown in tabulated form in Table I. Analyses 1–10, inclusive, are from oil wells drilled on the South Mountain dome, analyses 11 and 12 are from wells drilled on the Shiells' Canyon dome, and analyses 13–18, inclusive, are from a prospect well drilled in Wiley Canyon, on the Oak Ridge uplift, some three miles east of Shiells' Canyon. The analyses from the South Mountain and Shiells' Canyon fields are of waters which occur in intimate association with oil, being either "top waters," "intermediate waters," or "edge waters." The

waters from the well in the Wiley Canyon district, on the other hand, are apparently not associated in any way with oil, as this well did not penetrate oil sand.

By referring to Table I, it will be seen that, excepting certain shallow waters, the analyses represent chloride waters in which calcium chloride is generally present, often in such amount as to equal or exceed the quantity of sodium chloride. These waters are comparatively dilute, their concentrations varying from 20 to 100 per cent, as compared with ocean water, the more typical brines having concentrations of 50 to 75 per cent of that of ocean water. Other outstanding characteristics of these waters are: the very low content of magnesium as compared with calcium, and the low carbonate and sulphate content of all the waters, excepting those from very shallow depths.

When the analyses are recast into the form showing properties of reaction (see Table I) their outstanding features are seen to be: (1) high primary salinity (sodium salinity), (2) high secondary salinity (calcium-magnesium salinity), (3) complete lack of primary alkalinity (sodium carbonate), and (4) low secondary alkalinity (calcium-magnesium carbonate).

The analyses in Table I are arranged, for each field, in the order of depth at which the water was found. Referring to the sequence of analyses of waters from South Mountain, it may be seen that, (1) the shallow waters, as represented by analyses 1 and 2, while high in chlorides, yet may contain an appreciable quantity of carbonates; (2) the waters from intermediate depths, samples 3, 4, and 5, from depths of 687 to 2,184 feet, are chloride waters in which the reaction value ratio of calcium chloride to sodium chloride varies from 1:8 to about 1:1; and (3) the waters from lower levels, 3,178 to 4,712 feet depth, are chloride waters in which the ratio of calcium chloride to sodium chloride varies from about 1:1 to 3:1.

In the sequence of samples from Wiley Canyon it will be seen that all of the analyses are of chloride waters, and that from 48 to 1,762 feet depth the ratio calcium chloride to sodium chloride varies from 1:9 to about 1:1, while from 3,760 to 4,970 feet this relationship is reversed, so that in the same way as in the deeper South Mountain waters, the calcium chloride exceeds the sodium chloride in the ratio of about 2:1.

TABLE I*

CHEMICAL PROPERTIES OF TYPICAL WATERS FROM WELLS DRILLED IN THE SESPE FORMATION IN FIELDS ALONG THE SOUTH BANK OF SANTA CLARA RIVER, VENTURA COUNTY, CALIFORNIA

FIELD AND WELL	DEPTH (FEET)	DISSOLVED SALTS IN GRAINS PER GALLON									PROPERTIES OF REACTION (PERCENTAGES)			
		$CaCO_3$	$CaSO_4$	$CaCl_2$	$MgCO_3$	$MgCl_2$	Na_2CO_3	$MgSO_4$	Na_2SO_4	NaCl	Total Solids	Primary Salinity	Secondary Salinity	Primary Alkalinity	Secondary Alkalinity
South Mountain:															
1. S. P., No. 18...	479	.....	.....	59.6	4.0	48.2	.....	2.2	.....	1,840.6	1,954.6	93.4	6.4	.....	0.2
2. W., No. 14.....	611	126.0	.....	.....	17.3	.....	576.2	.....	1.1	550.6	1,271.2	40.6	.....	46.8	12.6
3. W., No. 15.....	687	.....	.....	129.8	.....	25.8	.....	0.9	.....	1,338.6	1,495.1	88.7	11.3	.....	.....
4. H., No. 8.....	2,037	.....	.....	904.0	.....	44.1	.....	.....	.....	809.3	1,757.4	44.6	55.4	.....	.....
5. S. P., No. 1....	2,184	.....	12.4	90.4	.....	.....	.....	.....	.....	351.9	454.7	76.8	23.2	.....	.....
6. H., No. 12.....	3,178	.....	.....	235.4	.....	0.9	.....	13.9	.....	181.9	432.1	41.4	58.6	.....	.....
7. S. P., No. 18...	3,246	.....	.....	674.6	.....	10.7	.....	4.8	.....	409.0	1,099.1	36.2	63.8	.....	.....
8. W., No. 6.....	3,672	48.5	5.1	1,177.0	0.2	.....	.....	.....	.....	388.6	1,619.4	23.0	73.4	.....	3.6
9. W., No. 13.....	4,230	13.6	12.5	101.0	4.0	.....	.....	.....	.....	68.7	199.8	33.2	56.6	.....	10.2
10. G. R., No. 2...	4,712	14.6	4.1	998.2	0.3	.....	.....	.....	.....	805.9	1,823.1	43.0	56.0	.....	1.0
Shiells' Canyon:															
11. Shiells, No. 85A	2,507	1.0	14.5	646.7	tr.	.....	.....	.....	.....	294.0	956.2	29.6	70.2	.....	0.2
12. Shiells, No. 25..	2,579	63.1	10.2	1,571.4	tr.	.....	.....	.....	.....	441.3	2,086.0	20.2	76.4	.....	3.4
Wiley Canyon:															
13. V. R., No. 2....	48	.....	89.2	.....	6.5	.....	.....	.....	25.6	47.1	168.4	44.4	49.8	.....	5.8
14. V. R., No. 2....	200	.....	76.1	.....	21.7	.....	.....	49.1	202.6	23.0	371.5	57.0	34.0	.....	9.0
15. V. R., No. 2....	770	.....	49.5	218.9	.....	.....	.....	.....	.....	1,007.5	1,275.9	78.6	21.4	.....	.....
16. V. R., No. 2....	1,762	9.4	12.7	49.5	.....	.....	.....	.....	.....	600.0	671.6	89.0	9.4	.....	1.6
17. V. R., No. 2....	3,760	.....	.....	1,287.4	.....	28.3	.....	6.1	.....	698.4	2,020.2	33.4	66.6	.....	.....
18. V. R., No. 2....	4,970	45.9	31.3	890.8	6.0	.....	.....	.....	.....	647.6	1,621.6	38.6	57.8	.....	3.6

* Analyses by M. T. Kendall.

The shallow carbonate water from South Mountain is considered to represent a mixture of downward-moving meteoric water with the normal chloride water of the Sespe formation. Its present chemical characteristics are therefore of recent acquisition, and this water, represented by analysis 2, Table I, will be dismissed from further consideration.

As noted previously, the South Mountain and Wiley Canyon sequences exhibit the phenomenon of increasing calcium salinity

TABLE II

ANALYSES OF WATERS FROM WILEY CANYON AND SOUTH MOUNTAIN

SALT	WILEY CANYON	SOUTH MOUNTAIN	
	Well V. R. No. 2 (Depth 3,800 Feet)	Well H. No. 6 (Depth 3,285 Feet)	Well W. No. 9 (Depth 3,622 Feet)
$CaCl_2$	832.60	964.84	862.64
NaCl	682.20	623.64	591.87
$MgCl_2$	9.40	12.90	5.91
KCl	None	12.61	11.50
$CaCO_3$	2.41	None	None
$Ca(HCO_3)_2$	23.64	1.31	1.17
$CaSO_4$	26.08	1.46	6.86
$Na_2B_4O_7$	10.80	Trace	Trace
$MgBr_2$	None	6.22	3.92
KI	None	1.57	.50
Total (grains per gal.)	1,587.13	1,624.55	1,484.37

with increasing depth. The sequence of Wiley Canyon waters exhibits an increasing concentration of total salts with increasing depth, but no such relationship seems to hold for the South Mountain waters.

The Shiells' Canyon waters exhibit no characteristics differing from those of the other two regions, excepting that they appear to attain the features of the deeper waters of Wiley Canyon and South Mountain at lesser depths.

For the purpose of ascertaining certain of the rarer constituents of these waters, three rather complete analyses were obtained, which are presented in Table II.

The analysis of water from V. R. No. 2 well, made by Smith-

Emery Company, was from water encountered at a depth of 3,800 feet which was under sufficient head to flow steadily. Inasmuch as waters both above and below this point had been cased off, and the sample collected from flow between casings some time after flow was established, the analysis is considered representative. The analyses H. No. 6 and W. No. 9 are of samples of water collected by bailers from the bottoms of the wells. As the upper waters had been cased off, these analyses are considered characteristic of the waters of the South Mountain field from these depths.

The outstanding characteristics of the waters found in the Sespe formation along the Oak Ridge–South Mountain uplift are: (1) they are chloride waters in which calcium chloride is generally present, often in amount exceeding that of sodium chloride; (2) they are not of high concentration, generally 50 to 75 per cent weight of dissolved salts, as compared to ocean water; (3) they have very low content of magnesium as compared to calcium; (4) potassium, bromine, and iodine are present in very small amounts as compared with sea water; (5) the ratio of $CaCl_2$ to NaCl increases with depth.

COMPARISON WITH CALCIUM CHLORIDE BRINES FROM OTHER LOCALITIES

A search of the literature has been made in an endeavor to find analyses of waters from other parts of the world which are comparable to the calcium chloride waters of Ventura County. Table III presents characteristic analyses of calcium chloride waters from all regions of their occurrence which have come to our attention. This table also presents, for comparative purposes, analyses of sea water and of natural and artificial bitterns. Certain waters from the Buena Vista Hills and Midway Valley regions,[1] Kern County, California, and certain waters from the Los Angeles basin are known to contain appreciable quantities of calcium chloride, or magnesium chloride, or both, but in these waters the ratio of calcium plus magnesium chlorides to sodium chloride is in general low, from 1:18 to 1:6, while in one exceptional case the ratio is 1:3. These waters are not considered comparable to the Ventura County brines, and will not be considered further, as it is believed that they are, in common

[1] G. S. Rogers, *U. S. Geol. Survey Professional Paper 117* (1919), pp. 84, 85.

TABLE III

COMPARISON OF VARIOUS TYPES OF CHLORIDE WATERS

Salt	Ocean Water		Artificial Bitterns Derived from Ocean Water		Natural Bitterns			Mine Waters			Oil- and Gas-Well Waters								
											Appalachian			Oklahoma		Texas	California		
																	South Mountain Field		Wiley Canyon
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ca	1.20	1.18	0.26	.....	4.37	2.01	.10	17.49	30.78	20.56	10.88*	14.68	10.90	9.76	6.27	10.89	18.52	27.46	20.09	19.89
Mg	3.71	3.59	3.72	10.05	13.62	11.13	17.55	1.21	0.01	6.82	0.94	0.65	0.95	0.74	1.53	0.93	0.63	tr.	tr.	0.25
Na	30.54	31.08	32.06	20.39	13.55	19.90	11.27	18.36	5.63	7.57	24.51	21.01	25.32	27.57	29.38	22.20	18.10	9.43	17.38	16.92
K	1.11	.71	.78	2.25	.....	.....	.....	0.67	.....	tr.	1.97	1.41	0.67	tr.	0.77	2.81	.....	.....	.....	.....
CO_3	.05	.18	.....	.....	tr.	.....	.04	0.48	0.01	.....	.....	.....	.....	.....	.....	.....	.....	1.80	0.50	0.75
HCO_3	.37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.74
SO_4	7.68	7.72	5.78	14.64	0.28	.....	6.82	0.13	0.01	5.42	0.02	0.40	0.17	0.74	tr.	16.44	.....	0.22	0.15	1.32
Cl	55.21	54.39	56.18	49.99	68.15	66.96	64.22	61.66	63.56	59.63	61.42	60.95	61.44	61.19	61.74	46.73	62.75	61.09	61.88	60.13
Br, I	.19	1.15	1.22	2.68	.....	.....	.....	.....	.....	.....	0.26	0.90	0.55	tr.	0.31	.....	.....	.....	.....	.....
Total	100.00	100.00	100.00	100.00	99.97	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total dissolved solids (grams per liter)	34.0–38.33	38.63	333.31	426.12	233.0†	300.1†	265.0†	36.0†	212.3†	?	319.35	276.6	179.7	135.3	130.7	103.39	30.10	27.80	31.25	27.08

* Includes 1.31 strontium.

† Parts per thousand.

NOTES TO TABLE III

1. Mean of 77 analyses of ocean water, collected by Challenger expedition, W. Dittmar, analyst. Analysis recast by R. C. Wells, *U.S.G.S. Professional Paper 120-A* (1918), p. 15.
2. Mediterranean ocean water, J. Usiglio, analyst. Recast by F. W. Clarke, *U.S.G.S. Bull. 216* (1916), p. 219.
3. Mediterranean water, concentrated from density 1.0258 to 1.21. Reference same as 2.
4. Mediterranean water, concentrated from density 1.0258 to 1.264. Reference same as 2.
5. Dead Sea, Palestine, F. W. Clarke, *U.S.G.S. Bull. 616* (1916), p. 174.
6. Red Lake, Crimea. Same reference as 5.
7. Elton Lake, Russia. Same reference as 5.
8. Silver Islet Mine, Lake Superior, F. D. Adams, analyst. *Ann. Report. G. S. Can.*, new series, Vol. 1 (1885), p. 17 M.
9. Quincy Mine, Hancock, Michigan, G. Steiger, analyst. F. W. Clarke, *U.S.G.S. Bull. 616* (1916), p. 185.
10. Germania Mine, Hurley, Michigan. From vug on ninth level. A. C. Lane, *Jour. Can. Min. Inst.*, Vol. 12 (1909), p. 114.
11. Washington County, Pennsylvania, gas well 8 miles southwest of Imperial. Brine from 6,300 feet depth, from early Devonian sandstone, George Steiger, analyst. *U.S.G.S. Water Supply Paper 364* (1914), p. 9.
12. Vinton County, Ohio, Southern Oil Co., well 2,100 feet depth, J. A. Cullen, analyst. W. C. Phalen, *U.S.G.S. Bull. 669*, p. 232.
13. Harrison County, West Virginia, South Penn Oil Co., 50 foot water sand at 2,094 feet depth, J. A. Cullen, analyst. W. C. Phalen, *ibid.*, p. 231.
14. Tulsa County, Oklahoma, oil well, depth 1,148 feet in Chreokee formation of Pennsylvanian age, R. F. Gardiner, analyst. W. C. Phalen, *ibid.*, p. 238.
15. Tulsa County, Oklahoma, oil well, depth 1,178 feet, Cherokee formation, J. A. Cullen, analyst. Reference same as 14.
16. Spur, Texas, well in Cisco formation, probably from 2,200 feet depth (Cisco is marine Pennsylvanian), S. H. Warrell, analyst. J. A. Udden, *Texas University, Bull. No. 28*, Science Series, pp. 82–89.
17. South Mountain oil field, Ventura County, California. Brine from Harvey well No. 8, depth 2,037 feet, M. T. Kendall, analyst.
18. South Mountain oil field, Ventura County, California. Brine from Willard well No. 6, depth 3,672 feet, M. T. Kendall, analyst.
19. South Mountain oil field, Ventura County, California. Brine from Geo. Richardson well No. 2, depth 4,712 feet, M. T. Kendall, analyst
20. Wiley Canyon, Ventura County, California. Brine from V. R. well No. 2, depth 3,800 feet, M. T. Kendall, analyst.

with other California oil-field waters from the San Joaquin Valley and Los Angeles basin, connate sea-waters in various stages of modification.

Table III exhibits the dissolved salt-content of the various waters, expressed in percentage of ions by weight, compared to weight of total dissolved salts. By referring to the table it will be seen that, whereas the Ventura County waters exhibit certain resemblances to other waters in chemical character of dissolved salts, they have one characteristic which sets them off as quite dissimilar to all of the other examples, viz., the Ventura waters are very dilute in comparison with the other oil-field waters, and also in comparison with the mine waters and bitterns.

Other important characteristics in which the Ventura waters differ from the other oil-field brines are: (1) their very low content of iodine, bromine, and potassium, and (2) their high Ca:Na ratio. The presence of borate in the Wiley Canyon water has already been noted. While it is improbable that any test for borate was made in analyzing the waters from the Appalachian and Oklahoma fields, it is thought to be unlikely that they contain borate in appreciable quantity, and if this surmise is correct, the presence of borate constitutes a third feature which marks the Ventura waters as dissimilar to the other oil-field brines.

The Ventura waters resemble the other oil-field brines in two respects, (1) high chlorine content with very low sulphate and carbonate content, and (2) high ratio of calcium to magnesium.

The Ventura waters exhibit a remarkable resemblance to the Lake Superior mine waters (analyses 8, 9, and 10, Table III) and particularly in the case of the water from Silver Islet mine (analysis 8) as compared to that from Harvey well No. 8, South Mountain field (analysis 17).

The Ventura waters bear little resemblance either to natural or artificial bitterns. In the first place, in order to produce a bittern in which the sum of calcium and magnesium exceeds the content of sodium, it is necessary to concentrate a solution of sea water, or of the usual types of river water, to a degree far beyond that of the Ventura waters. Other points of dissimilarity are: (1) the Mg:Ca ratio in bitterns varies from 3:1 to infinity, while in Ventura waters

the relationship is reversed, the ratio being 1:30 to practically zero; (2) artificial bitterns, derived from sea water, contain considerable potassium, bromine, and iodine, all of which are in only minute quantity in the Ventura waters; (3) the bitterns in general contain more sulphate and, conversely, less chloride than the Ventura waters.

In summary, it may be said that the Ventura waters find their closest analogues in the Lake Superior mine waters, that to a lesser degree they resemble the Appalachian and Oklahoma oil-field brines, that they differ markedly from natural and artificial bitterns, and that they differ from all of these types of calcium chloride waters in that they are much less concentrated. The very low content of iodine and bromine in the Ventura waters is considered an especially important feature in which these waters differ from other brines and bitterns.

ORIGIN OF CALCIUM CHLORIDE WATERS

A search of geologic literature shows that papers dealing with calcium chloride brines and their origin are far from numerous. However, several contributions have been made to this subject during the past fifty years, and the various ideas which have been advanced will be briefly reviewed.

In 1875 T. Sterry Hunt[1] advanced the idea that the deep-seated calcium chloride waters of Ontario are long-buried bitterns derived by evaporation from the waters of ancient seas in which calcium was more abundant than in the present-day ocean. This theory was supported by A. C. Lane,[2] who considered the highly concentrated Huronian brines high in calcium chloride, which are found in many of the Michigan iron and copper mines, to be bitterns derived from a primordial sea water that was a weak solution of calcium and other chlorides.

This theory of a primordial calcium chloride sea water has nothing to commend it, as (1) it is difficult to see how life could have existed in marine waters of this character, and (2) it does not adequately explain the numerous other occurrences of calcium chloride

[1] *Chemical and Geological Essays*, Boston, 1875, p. 117.

[2] "Mine Waters," *Proc. Lake Superior Min. Inst.*, Vol. 13 (1908), pp. 63 ff., and "Michigan Iron Mines and Their Mine Waters," *Jour. Canadian Min. Inst.*, Vol. 12 (1909), pp. 114 ff.

waters having a rather wide geologic range. It can be dismissed as a possible explanation of the calcium chloride waters under consideration, as it is fairly certain that the composition of the ocean in Tertiary time was not essentially different from that at present. Furthermore, the Sespe beds in which the Ventura County calcium chloride waters occur are not marine, but continental.

Later C. W. Washburne[1] advanced the theory that calcium, magnesium, and sodium chlorides may have been introduced into underground brines by emanations from deep-seated basic magmas. If this were true, the composition of the deeper underground waters should be essentially the same in any one province, irrespective of the beds in which they are found. That this is not the case is clearly shown in many places, notably in Ventura County, where the calcium chloride waters from the South Mountain and Shiells' Canyon fields differ widely from the modified connate sea-waters found in the Ventura Avenue field not far distant.

The most thorough work on the subject is by Mills and Wells,[2] who explain the high chlorine content and very high concentration of certain Appalachian oil-field brines as due to changes in the waters subsequent to their inclusion in the sediments. These changes are supposedly due to solution of certain rock constituents, to organo-chemical processes, to chemical reactions brought about by the mixing of waters, to reactions due to heat, to reactions between dissolved constituents of the waters and certain constituents of the rocks, and, most important, in their opinion, to changes and concentration brought about by the drying effect of escaping gases. However applicable this theory of the concentration and modification of the waters by escaping gases may be to the Appalachian waters, it does not seem to apply to the calcium chloride waters of Ventura County, as the latter are of comparatively low concentration.

The lithologic character of the Sespe formation, the lack of marine fossils, and the presence of mammalian remains (species of

[1] "Chlorides in Oil Field Waters," *Trans. Amer. Inst. Min. Eng.*, Vol. 40 (1914), pp. 687–93.

[2] "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U.S.G.S. Bull. 693*, 1919.

Hypertragulus and Oreodon) are considered as adequate proof that the Sespe is continental and not marine. The very small amount of bromine and iodine in the underground waters is further proof that these are not marine sediments and that the waters they contain are not connate sea-water. While this somewhat simplifies the task of determining the probable origin of the calcium chloride waters under consideration, there are a number of possible means by which they could have been formed.

Broadly speaking, there are two possible sources of the water found at present in the Sespe. Either the water is connate, that is, trapped in the sediments at the time of their deposition, or it has been introduced into the Sespe beds since their formation. The oil found in the Sespe must have originated outside of this formation, as the Sespe contains no shales that would seem to be a possible source of oil. Oil in any quantity is generally conceded to have been formed from beds of marine origin. Should water have been introduced with the oil, this water should also have had a marine origin. The absence of any appreciable amounts of potassium, iodine, and bromine indicate that the waters are not marine, and hence it may be assumed that the waters were not introduced with the oil.

Assuming that the waters are connate and that the Sespe is non-marine, the waters could have originated in a variety of ways, as follows:

a) The waters entering the area in which the Sespe accumulated may have contained calcium chloride in excess of other constituents. This possibility seems worthy of little consideration, as normal stream waters are not of this character and it would be necessary to postulate a very unnatural source for the stream waters entering the area in which the Sespe accumulated. There is nothing in the known pre-Sespe geology of the region to suggest that this might have been the case.

b) Lake waters in an arid region may have been concentrated to calcium chloride bitterns by evaporation, with removal of less soluble substances by precipitation. While this is a very plausible theory, it is not supported by the known facts. In the first place the waters are not sufficiently concentrated to be classed as bitterns. They may, of course, have been concentrated to bitterns and sub-

sequently diluted; but the amount of magnesium present is too low, with respect to the other constituents, to indicate that the waters, as we know them now, are diluted bitterns. Furthermore, if concentration had proceeded to the formation of a bittern, we would expect to find considerable deposits of limestone, gypsum, and rock salt in the Sespe beds. Thin layers of limestone occasionally occur, and the shales contain crusts of gypsum, but there are no beds of gypsum or rock salt of such importance as to indicate that the concentration of the waters in lake basins ever progressed to the point of bittern formation. While the underground Sespe waters are much more highly concentrated than normal stream waters, indicating the probability that a certain amount of concentration was brought about by evaporation and precipitation, yet this process appears to have played only a minor part in the formation of the calcium chloride waters under consideration.

c) The original waters may have been modified by reaction with oil. Although the calcium chloride waters from the South Mountain and Shiells' Canyon oil fields are intimately associated with oil, similar waters are found to a depth of 5,000 feet in the Wiley Canyon dome, where no oil is known to occur. For this reason it does not seem probable that the present composition of the waters is due to reaction with oil.

d) The original waters may have been modified by reaction with volcanic rocks, either during the deposition of the Sespe or by reaction with subsequent intrusions. There is no evidence that there was any igneous activity contemporaneous with the deposition of any part of the Sespe. Igneous activity, resulting in intrusions, flows, agglomerates, and tuffs, is known to have taken place during the accumulation of the Monterey series, some time after the Sespe formation was laid down. The feeders for the intrusions and extrusions are known to have cut the Sespe beds on their way to the surface, and it is possible that the underground waters of the Sespe were modified by contact with these rocks. The presence of boron in the waters would suggest that such may have been the case. However, it is thought that reaction of the waters with volcanic rock or the addition of material to the waters through volcanic emanations could have been only a very minor factor in producing the calcium

chloride waters. The reasons for this conclusion are that the areas in which these waters occur are at some distance from the chief center of Miocene vulcanism in this district, and furthermore, that, in two of the areas where these waters have been found, there is no evidence of the Sespe having been intruded by any volcanic rocks. Although it is conceded that volcanic emanations can affect the character of underground waters at considerable distances from their point of introduction into the reservoir rock, it is not thought that such could have been the case with the waters under consideration, since the movement of Sespe waters is away from the Oak Ridge anticline, and toward the center of vulcanism.

e) The original waters may have been modified by reaction with minerals or salts, either during accumulation of the Sespe beds or after their deposition. The writers believe that this theory merits very serious consideration, since it does not conflict with any of the known geological facts and since the chemical reactions which would take place in such a process are possible. Although our present knowledge of the chemistry of soils and of the exchange of bases does not offer full support for every stage of this process, nevertheless it is thought that reaction between connate waters and materials of the containing rocks is the most satisfactory explanation of the origin of the calcium chloride waters which can now be offered.

The following is a brief outline of the writers' conception of the history of the waters and the changes which have taken place since their entrance into the area in which the Sespe accumulated. The streams entering the Sespe basin contributed waters whose chemical character probably differed but little from average river waters as we know them today. Such a water would be essentially a carbonate water, with lesser amounts of sulphate and chloride. Of the bases, lime would be most important, followed by soda, but with appreciable quantities of magnesia. It is conceived that such a water, accumulating in arid basins, would become modified through deposition of carbonates and sulphates which would enter the accumulating sediments as constituent minerals, leaving a residual liquor composed of sodium, magnesium, and calcium chlorides, with minor amounts of sulphates and carbonates. There are no beds of pure gypsum in the Sespe formation, and comparatively few beds of

limestone. However, gypsum is present in disseminated form throughout these sediments, and it is thought that enough lime is also present in disseminated form to account for all the salts which would be precipitated in accordance with this theory. In such a water the sodium would probably exceed the sum of the calcium and magnesium, and the magnesium would probably exceed the calcium. An examination of numerous analyses of underground waters, which appear to be altered connate sea-water, reveals the fact that almost invariably calcium is in excess of magnesium, whereas in sea water magnesium exceeds calcium. It is therefore evident that in the alteration of a water containing both lime and magnesia the increase of lime at the expense of magnesia is a general phenomenon. This is probably effected through reaction between the water and its containing rock, but whatever the cause, this change could have taken place in the Sespe water and have resulted in the water of high Ca:Mg ratio which we find today.

While it is a generally accepted view that a change in the Ca:Mg ratio does take place in buried waters through reaction between solution and rock, an analogous explanation for the increase of the Ca:Na ratio is perhaps not generally accepted. In support of the idea that the ratio of lime to soda in a chloride solution may be increased through a reaction between solution and rock it may be said that (1) such a reaction is possible, as witness the equation employed to represent the regeneration of Permutit water-softener:

$CaO \cdot Al_2O_3 \cdot 2SiO_2$ plus $2NaCl = Na_2O \cdot Al_2O_3 \cdot 2SiO_2$ plus $CaCl_2$

Calcium zeolite ("Run-down" Permutit) plus common salt =
Sodium zeolite (Permutit) plus Calcium Chloride.

Zeolites are well-known rock-forming minerals. While it is doubtful that zeolites were ever present in appreciable quantity in the Sespe rocks, yet other lime silicates of similar reacting properties may have been present. (2) Investigation of the chemistry of soils has revealed the presence of certain amorphous calcium silicates, which are thought to be particularly abundant in arid regions. These silicates, like the zeolites, have the property of taking sodium from a solution and yielding calcium to the same solution.

It has been found that when soils containing calcium have been

treated with either pure sodium-chloride solutions, or mixtures of sodium- and calcium-chlorides in solution, that the ratio of Ca:Na in the resulting solution does not become greater than 1:2, in the case of very dilute solutions. When the concentration of the solutions is one-tenth normal, or greater, the Ca:Na ratio of the resulting solution can be no greater than 1:5.[1]

These results would indicate that, if the reactions between the Sespe waters and their enclosing rocks followed exactly the same laws as the soils, our theory is unsound. However, the effect, on the exchange of bases, of salts in the solution other than the sodium- and calcium-chlorides is unknown, as are also the effects of the temperature and pressure existing at the depths at which part of the reactions postulated must have taken place. The effect of these factors can only be determined by experiments, which are beyond the scope of the present work.

All but one of the analyses presented were made by Mr. M. T. Kendall at the Ventura Refinery at Fillmore, to whom we wish to express our thanks. One analysis was made by the Smith-Emery Company, commercial chemists.

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THE STATUS OF AMERICANS IN PETROLEUM DEVELOPMENTS OF EUROPE AND ASIA

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ABSTRACT

This paper deals with the major known petroleum regions of Asia, also the fields of Southern Europe, such as Rumania and Russian Caucasia, which are geographically related to Asiatic districts east of the Caspian Sea. Consideration is given to future prospects, rather than to a review of the past. Geological conditions are set forth briefly and industrial and political matters are touched upon in so far as they have a bearing upon future developments and may affect American participation in them. Such facts as may indicate the relative importance of the oil regions are cited, and events of recent history are reviewed which show the reasons for the failure of Americans to become established in these countries. The oil regions will, so far as possible, be grouped geologically into provinces, and the extent of these provinces defined by reference to political subdivisions. By grouping into the stratigraphic and structural provinces as shown by the heavy lines on the accompanying map (Plate 19), the areas are indicated in which there is a continuity of conditions, such as major lines of folding and general similarity of formations, but not, of course, a continuity of oil accumulations. The map, however, aims to indicate roughly the lines along which future oil fields are most likely to be developed. The lines connecting developed oil regions do not represent continuous single anticlines, but in some cases groups of folds or other structural conditions favorable to oil accumulation, also areas of similar stratigraphy.

The writer has spent a number of years recently in both the Far East and the Near East, having visited many of the regions discussed, conferred with government geologists and others associated with American or British companies, fresh from the study of some of the more important oil districts, and has also had some experience with negotiations for oriental oil lands. The following discussion is built upon such sources of information as those mentioned and upon a certain amount of personal knowledge, more largely than upon a search of petroleum literature. Dependence has been placed upon reliable oil journals for recent events. It is admitted that others, especially English geologists, have much more detailed information upon the fields discussed, but the writer feels that the conclusions expressed are sufficiently justified by the information in his possession.

RUMANIA—CAUCASIA—TRANSCASPIA

The first and most important structural province includes Caucasia as its principal area of production. Oil has been produced there continuously since the days of Marco Polo. Baku is about the middle point on a great structural belt continuous with the Himalaya uplift, passing along the north boundary of Persia, through southwestern Transcaspia, under the Caspian Sea, along the Caucasus range, westward again through the Crimea, and thence along the

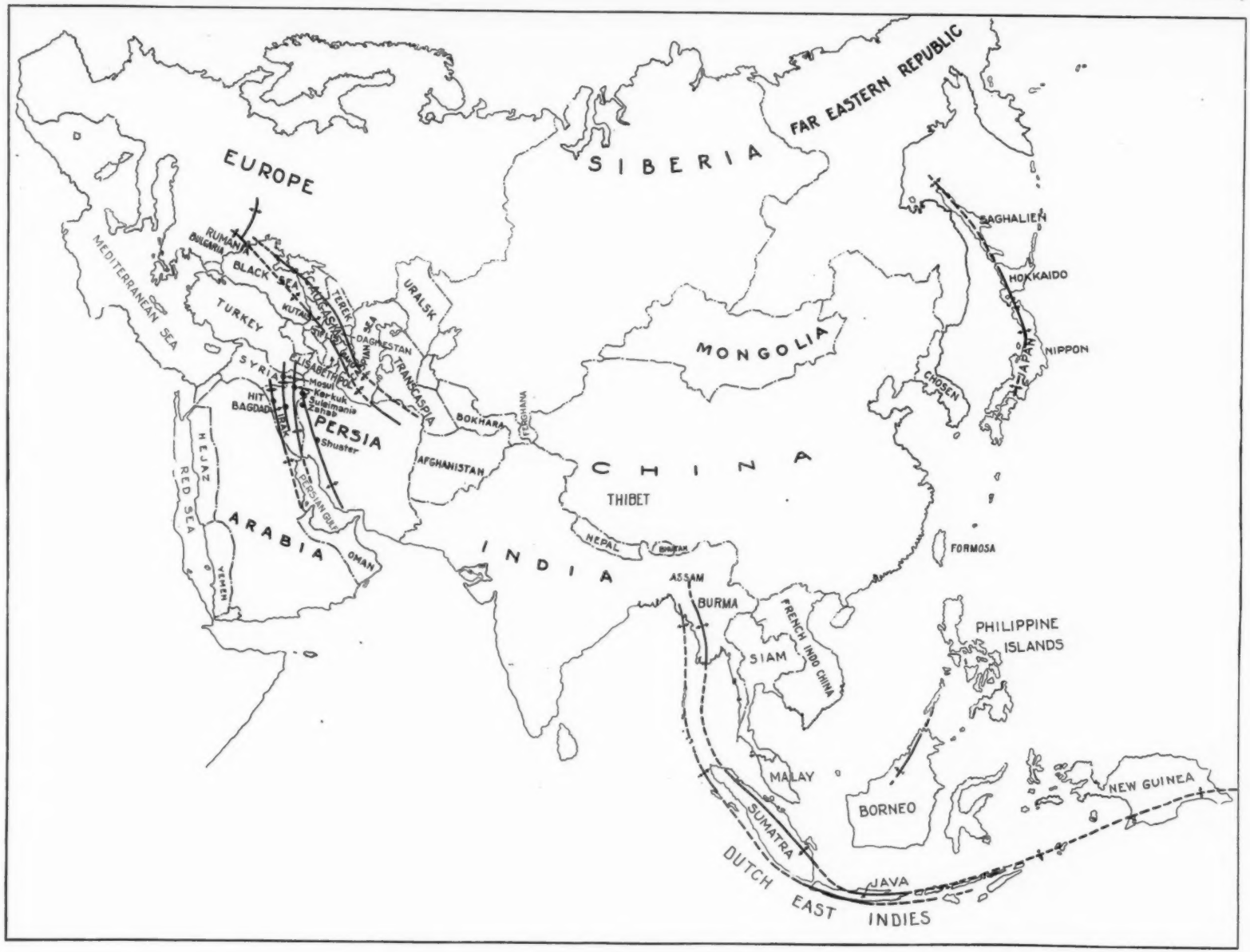
Transylvanian Alps of Rumania, a distance throughout which, in every political subdivision mentioned, petroleum in quantity has been found.

GEOLOGY

Marine Cretaceous beds spread over a larger area than subsequent formations in the oil-producing belt so defined. The Eocene sea receded, its north shore extending, in general, due east from Denmark through the latitude of Moscow, and its southerly limits reaching barely beyond the present south shore of the western Mediterranean. Such correlations as have been made indicate that it widened eastward across Egypt, Arabia, and Persia, and connected with the Indian Ocean. The marine Miocene, from which most of past oil production has been made, was laid down in a sea which had still more radically shrunk, and the Miocene beds in the Caucasus belt are generally shore-line and shallow-water deposits. The Miocene sea may be regarded as an arm of the Mediterranean extending exactly along the line of the present Rumania-Caucasia major fold and having narrow limits north and south, including Bulgaria and Rumania, little more than the width of Caucasia, and only part of the Caspian Sea. The period closed with alternating marine and fresh-water deposits, and succeeding Pliocene sedimentation was largely lacustrine.

BAKU

Most of the wells in the Baku field are only seven or eight hundred feet deep in Tertiary beds (Sabuntchi series). It has been a field of very large flowing wells and still is, in spite of inefficient management of wells. In the early days many of the wells were uncontrollable and the oil went to waste. In recent years there has been much deterioration in the equipment of the district, which is largely responsible for the growing impression that the field is seriously declining. Water has, in fact, invaded some of the upper Tertiary sands. As far back as 1916 there were over two thousand wells standing idle, which, by cleaning out or drilling deeper, could probably have resumed production. The percentage of idle wells under the Soviet régime has greatly increased. Production of 53,000,000 barrels in 1916 from Baku has fallen to considerably less


EUROPE
SIBERIA
FAR EASTERN REPUBLIC
MEDITERRANEAN SEA
RUMANIA
BULGARIA
BLACK SEA
TURKEY
SYRIA
KUTAIS
TIFLIS
TEREK
GROZNY
BAKU
DAGHESTAN
URALSK
TRANSCASPIA
BOKHARA
TURKESTAN
AFGHANISTAN
MONGOLIA
CHINA
THIBET
NEPAL
BHUTAN
INDIA
ASSAM
BURMA
SIAM
FRENCH INDO CHINA
PHILIPPINE ISLANDS
FORMOSA
CHOSEN
JAPAN
NIPPON
HOKKAIDO
SAGHALIEN
ELISABETHPOL
Mosul
Kerkuk
Suleimania
Zarrab
Shuster
HIT
BAGDAD
IRAK
PERSIA
PERSIAN GULF
HEJAZ
RED SEA
YEMEN
ARABIA
OMAN
MALAY
BORNEO
SUMATRA
JAVA
NEW GUINEA
DUTCH EAST INDIES

than half that amount. Field labor is now entirely unsatisfactory, and there is a great lack of skilled supervision. The same is generally true of the other Russian fields. Little new drilling has been done since the war until last year, but to illustrate the persistent vigor of the field, May 28, 1924, a 12,000-barrel well was brought in at 2,781 feet (Balakhai beds), the first development of the so-called "fifth horizon." On July 7 another gusher of about the same volume was completed in the "fourth" sand. Both wells yield high-gravity oil. The production in the region of the latter well has already been about 280,000 barrels per acre from the upper sands.

Brief reference should also be made to other separate Caucasian fields, mainly for the purpose of indicating the future possibilities in the Caspian–Black Sea belt.

DAGHESTAN

This small province adjoins the Baku region on the northwest and lies north of the Caucasus range. It was a productive area with quite a number of gushers up to 1904, when hot salt water came in. It is the only area in Caucasia in which this has happened.

TEREK

This province also lies in the northern foothills of the Caucasus, adjoining Daghestan on the west. The oil is all produced from Tertiary rocks in two districts two or three miles apart, Grosny and Mamakai. The annual production for this province was about 14,000,000 barrels in 1918. The Grosny field has been characterized by very large gushers. It is reported that one well in 1893, at a depth of 198 feet, spouted 200 to 300 feet through a 16-inch casing. Starting at 100,000 barrels per day and running down to 60,000 barrels at the end of six days, this well settled down to a steady flow of 30,000 barrels for about one year.

Soon afterward a well in the Mamakai structure came in at over 100,000 barrels. In this well oil was struck at 294 feet, but was cased off and the gusher came in at 462 feet with heavy oil, both sands being Miocene. Later drilling at other locations was carried much deeper into the Oligocene and resulted in the production of a light paraffin oil. The wells are now said to average around 2,000 feet

in depth, with a maximum depth of 3,000 feet. They are all in beds considered to be Tertiary, unconsolidated sands alternating with thick shales and some limestone and dolomite.

There are other structures in the province of Terek, but they have been given only enough development to show the presence of oil.

KUBAN

This province lies between Terek and the Black and Azof seas, with railway terminus and port at Noverossick on the Black Sea. The principal producing structures are at Maikop and Kudako. Kudako produces heavy oil at 150 to 300 feet, and paraffin oil at 650 to 900 feet. It is claimed that there has not been a dry hole in this field. Deeper drilling has been done in Maikop to a maximum of 5,000 feet, probably into the Cretaceous. Shallow oil is about 33° Baumé; deep oil is high gravity. Although in the two fields some wells have flowed up to 3,500 barrels a day, the pressure is generally much less than in the other Caucasian districts mentioned.

KUTAIS

Returning eastward and following along the south flanks of the Caucasus mountains, this province is the westernmost of the foothills areas. The oil fields lie just north of Batum, the Black Sea terminus of the Baku pipeline. Drilling has not been done, so far as is known to the writer, but the natives have for a long time produced oil for lubricants from pits along outcrops.

TIFLIS

In this province, next east of Kutais, there is some outcrop production by the inhabitants.

ELIZABETHPOL

This lies between Tiflis and Baku, and in it are two known structures distinguished by the seepage of paraffin oil from outcrops. This is collected and sold by natives for medicinal purposes. One well, drilled about three years ago, was a violent gusher, breaking the casing and choking itself. This is, therefore, likely to be in the future an oil district of importance.

CRIMEA

This is the next land area westward from Russian Caucasia on the same structural belt. It has made some oil production since 1864, but is still undeveloped and of uncertain promise for the future.

RUMANIA

In 1924 Rumania made a total production of about 14,000,000 barrels, which is an increase over previous years. It has about 1,000 producing wells. Large wells in the Rancu and Ochuiri fields, yielding 20,000 barrels and more daily, have been recently drilled in. The best oil horizons occur in the Miocene and Pliocene, which were laid down in the transition period between marine Miocene and lacustrine late Pliocene. The Carpathian line of uplift joins the Transylvanian Alps nearly at right angles from the north, and the combined influence of these two major folds has subjected the sediments along their flanks to most intricate folding and complex faulting.

GALICIA

Galicia, now a part of Poland, adjoins Rumania on the north and occupies the east foothills of the Carpathians. It has about 200 wells, producing nearly 5,000,000 barrels per year. Drilling conditions are probably more difficult than in any other field in the world. The saturated sands are at great depth, 4,000 to 5,000 feet, and the drill must pass through steep-dipping strata, alternately hard and unconsolidated Pliocene lake beds.

BULGARIA

This country is located in the area of the shallow arm of the Miocene sea, but south of the structural belt described above. Active geological reconnaissance has been carried on for the past three years by both British and American geologists. British interests now hold exclusive oil rights in about 1,250,000 acres in Bulgaria, located in four tracts, the largest in the center of the kingdom, just south of the Balkan mountains, the three others (1) at Providia on the Black Sea, close to the Rumanian frontier, (2) in the Maritza Valley, and (3) at Kostenitz. Seepages, proper structural conditions, and suitable sands have led geologists to make definite drilling recommendations in the past year.

TRANSCASPIA (EASTERN TURKESTAN)

This province undoubtedly has great potentialities. Although the whole area deserves study, the region of greatest immediate interest is that in line with the axis of the Caucasus uplift across the Caspian Sea. On the mainland, 100 miles inland from the railway terminus at Krasnovodsk, is a dome 3 miles by 1½ miles in size, which appears to be a shattered or collapsed anticline from which petroleum mixed with sand and ozokerite escapes to the surface in considerable quantities. There are also several so-called "mud volcanoes" which eject gas, mud, water, oil, and ozokerite. The government has drilled several shallow holes which have varied in production from 60 to 90 barrels per day. The Transcaspian Railway has from the beginning used oil from this province for fuel.

CHELEKEN ISLAND

Cheleken Island, also in the Caucasus belt near the coast of Transcaspia, is described as almost wholly made up of "cliffs saturated with petroleum." The island is now being drilled, and flowing wells are reported. Soviet authorities did 228,760 feet of drilling last year. This oil goes to the Baku refineries.

NORTHERN PERSIA

In northern Persia there are anticlines lying south of, and parallel with, the continuation of the Caucasus range, and corresponding to the folds of southern Caucasia. Oil has been discovered, but development has been retarded by political complications.

OTHER PETROLEUM DISTRICTS IN RUSSIA

The north Caspian provinces should be mentioned because they are promising for the future. The geologic structure of this region has not been worked out to any considerable extent. Oil showings have been reported in Astrakan, Saratoff, Samara in European Russia, and in Uralsk in Asiatic Russia. In these provinces the Cretaceous and early Tertiary are well represented.

In Uralsk at many points there are paraffin wax outcrops, and ozokerite deposits are found both on the surface and in drill holes. The principal geological work has been done along the lower courses of the Emba, Sagyz, and Ural rivers, and the whole region is gen-

erally referred to as the Emba field. English geologists have studied a structure at Gurieff, near the mouth of the Ural River, and predict that a big field will be developed. One inland field near Das Sor has had considerable development, and before the war supplied two 6-inch pipelines 45 miles long to Rakusha, a port on the Caspian Sea where there is a refinery in operation. In this district a gusher came in at 732 feet. Some nine or ten years ago drilling was done with satisfactory results on four different structures not far from Das Sor. It is believed no additional development has taken place under the Soviet régime. Production of the Emba district, formerly around 2,000,000 barrels per year, has decreased to a little over 1,000,000.

No record of oil reconnaissance in Bokhara and Samarkand is known to the writer, but there is a series of folds across these countries lying considerably north of, and roughly parallel with, the Caucasian uplift; and in Ferghana, a small Russian province adjoining Bokhara on the east, several flowing wells have been brought in and the field seems to be very promising. It is not so inaccessible as might at first appear, being within striking distance of transport on the Oxus River or on the Samarkand branch of the Siberian Railroad.

SIBERIA

In the main area of Siberia (including the territory of the Far-Eastern Republic) very little petroleum geology has been done. Except in Uralsk, Turkestan, and Ferghana, and possibly along the east coast, it is not generally promising. A great part of Siberia was probably a land area from early Paleozoic to the present, with the exception of a short period of marine invasion in Lower Cretaceous time.

PERSIA—MESOPOTAMIA (IRAK) STRUCTURAL PROVINCE

This constitutes a great "petroliferous province" next in importance in Asia to the highly productive Caucasus-Rumania belt just considered, particularly on account of its great possibilities for the future.

A broad northwest-southeast mountain range occupies Western Persia. Paralleling this range on the west is an anticlinal fold which appears to extend for some 800 miles along the west edge of Persia

through Bushire, Shuster, and Zohab, thence across the boundary for a considerable distance into Mesopotamia, passing west of Sulemania and along the west foot of the Kara Dagh range. The Shuster district, said to contain several individual domes, has been well developed and is the present source of crude supply of the Anglo-Persian Oil Company.

The last report of the chairman of the Anglo-Persian Company gives the information that the total production to date from one well, "F-7," has been 42,000,000 barrels. "B-17," one and three-fourths miles from "F-7," is now making 18,000 barrels per day. Conservation is practiced. Wells have been drilled down to cap rock ready to drill in. The chairman states production could be made 70,000,000 barrels per annum, but since it now supplies demands, the company does not propose greatly to increase production and thereby be obliged to increase refining and transport equipment. He remarks that big production could be made so suddenly that world-markets might be seriously disturbed. At the present time Persia, i.e., this company, is producing at the rate of nearly 50,000,000 barrels per year, and ranks fourth in world-production.

About thirty miles west of, and parallel with, the Shuster anticline is another along which are oil structures at Kerkuk, Tuz-Khurmatli, Kifri, Mendeli, and probably others. West of this, about 40 or 50 miles, is an anticlinal axis which determines much of the course of the Tigris River. The latter two lines of folding persist for several hundred miles. The last mentioned has high points upon it near the city of Mosul (the bone of contention at the Lausanne Peace Conference), at Zakhu, Kalah-Shergat, Tel-Kipara, and Baba-Gurgar. Along both of these anticlines are many small lakes of solid asphalt, gas emanations, and petroleum "springs." In the localities just named the natives have dug innumerable pits for collecting the oil.

A fourth anticline to the west directs a part of the lower course of the Euphrates. On it, ten miles or so below the town of Hit, is a great lake of fluid asphalt. In this region also the natives collect oil from seepages.

On these anticlines there are apparently many domes, as determined in earlier German reports and by British and American

geologists since the war, and the most extraordinary surface showings. The outcropping beds are Miocene, deposited in the main Mediterranean Sea, then connected with the Indian Ocean, but separated from the Caucasian arm above described by a long peninsula extending through northern Turkey and Armenia.

Natives refine in a crude fashion the oil from the Tigris and Kerkuk seepages, making a first-quality water-white illuminating oil. This is 20 per cent of the crude. They then get 25 per cent to 30 per cent yellow distillate, also used for illuminating. The residue is used as domestic fuel.

Sultan Abdul Hamid, before the Young Turk Revolution, had, as a private individual, gone through the due course of procedure and established, in his own name as a private citizen, title to practically all the Mesopotamian oil fields above described, then a part of the Turkish Empire. Abdul Hamid was deposed and the new government confiscated his oil properties. They were afterward claimed by the present Turkish government as its property, but having lost Mesopotamia in peace settlements, Turkey has also probably lost the oil fields. The new state of Irak, mandated to Great Britain, has been created in Mesopotamia, and British interests therefore occupy a favored position in the contest for Mesopotamian oil.

The formations and other general conditions in the Mesopotamian area, being identical with those in Persia at one end and very similar to those of Caucasia at the other, it is to be anticipated that Mesopotamia (Irak) will be an oil country of first magnitude.

BURMESE INDIA AND DUTCH EAST INDIES

Burma and the Dutch East Indies comprise what should probably be regarded as the third greatest petroliferous province of Asia and Europe.

BURMA

The mountain range lying between the lower third of the Irawaddy River and the Bay of Bengal was upfolded in late Tertiary. On both sides of this range are sedimentary beds ranging in age from the Tertiary down through the Paleozoic. Anticlines containing oil domes are found 40 to 50 miles away on each side of this range. Those on the west lie mostly under the sea, but appear on

several islands off the coast of the state of Arakhan. No deep holes have been drilled on these islands, but native hand-dug wells have made a considerable production. One well 66 feet deep developed a strong flow of gas. There are also some of the so-called "mud volcanoes" on the islands, caused by escaping gas under high pressure.

On the east side of the range a productive anticline has fortunately been exposed at places by the Irawaddy River, which meanders along its axis. Yenangyaung is the greatest producing field. It is a sharply defined dome about two miles long and a little less than a mile wide, with steep limbs. Wells range from 400 to 2,100 feet deep. Six hundred wells have been producing for over thirty years with sustained pressure. Specific gravity of the oil ranges from 0.74 to 0.90. Singu, 20 miles farther up the river, has fifty flowing wells. Yenangyat, still farther up, is a small structure and, though it has made considerable production, is now falling off. Mimbu, 18 miles south of Yenangyaung, is a small structure and is also falling off in production.

Burma is a difficult country to explore for oil because in most of the promising regions the surface is covered by jungle and deep alluvium.

South of the present producing field in Burma, structure mapping from outcrops will be impossible. This is the flood plain of the Irawaddy and there are few rock exposures. The promising belt west of the range passes under the sea south of Arakhan. Burma production is about 7,000,000 barrels per annum of high-gravity oil.

OTHER INDIAN DISTRICTS

Other Indian fields produce about 200,000 to 300,000 barrels per year, all of which is reported to come from Assam. There has been considerable exploratory drilling in Assam since 1894, but no deep drilling has been done. High-grade paraffin oil is produced. India proper deserves thorough structural study. The whole area south of the Himalayas has the same stratigraphic horizons as Burma, but until recently little petroleum geology had been done in this region. British geologists are now exploring actively. The geological conditions of the main structural belt of Burma continue through the Dutch East Indies.

DUTCH EAST INDIES

Commercial production started in Sumatra in 1892, and was soon followed by discoveries in Java and Borneo. In Sumatra and Java the oil fields lie on the northerly side of the mountain range, thus corresponding with the developed fields of Burma.

The Dutch islands now yield about 15,000,000 barrels per year, ranking the Netherlands as fifth in world-production. The total area of the islands is about five times that of Colorado. All oil has come from comparatively shallow wells in Miocene sands and in well-defined closed structures, in some cases in close proximity to active volcanoes.

Oil indications are found south of the range in Java and in some of the smaller islands of the chain east of Java, on Celebes and Muna Islands, and in western Dutch New Guinea. There are also good possibilities of extension of present producing areas. Prospecting is greatly hindered by the jungle, but not so much by lack of outcrops as in Burma.

Borneo lies in a separate structural province, but otherwise geological conditions are similar. It contributes considerable production. Production, refining, and marketing are under joint British-Dutch control. Little gasoline is made, but every effort is directed toward the recovery of kerosene. Too much cannot be made to satisfy Asia, and it is delivered to the remotest points throughout the continent. The Asiatic Petroleum Company (British) handles most of the marketing and is rapidly invading China and Indo-China where Standard Oil of New York formerly controlled the market situation.

NEW GUINEA

New Guinea, the largest island in the world, is now divided mostly between Holland and Great Britain. Here and in the Melanesian chain of islands situated along the Burma-Dutch Indies major fold, surface showings of oil have been found. In one small island a well is now making commercial production.

THE JAPANESE ARCHIPELAGO

This is a semisubmerged mountain chain including Sagalien, the Japanese islands, the Philippines, and Borneo.

JAPAN

Japan formerly possessed four oil districts. Now that it has permanently acquired all of Saghalien by treaty with Russia, its prospects for future oil are considerably increased. The most important producing structures are on the eastern slopes of the northern one-third of Nippon (Honshu), where systematic drilling has been done and considerable production has been made, but salt water now begins to encroach. Along the eastern shore of Hokkaido, the next island north, three localities have been tested by drilling, and one of them, Akita, has made considerable output. The oil has been found in the past mostly in late Tertiary beds at shallow depths, but in recent years drilling to 4,000 and 5,000 feet has found oil, probably in the Lower Cretaceous, which is well represented in outcrops and rich in fossils. Fields in North Saghalien have been favorably reported upon by American geologists. Formosa now yields a small amount, about 10,000 barrels per year.

Japanese production has dropped to less than 2,000,000 barrels per annum. Individual structures are small. Japanese geologists report a great number of them, but only twenty-five have been successfully drilled. Japan, even with Saghalien, has not a large known reserve of oil to count upon, or great prospects for the future.

Costs of production in Japan have risen so rapidly that operators have difficulty in competing with cheap crude and refined products from America, the Dutch Indies, and Burma. The government, however, is said to be stimulating some development to assure itself of a naval supply.

PHILIPPINES

Considerable geologizing and some drilling have been done, thus far without important results, in the Philippine Islands. Prospecting should not be abandoned, however, for the islands contain the sedimentary formations which are productive in Japan and the East Indies, and the same major structural conditions.

CHINA

China produces practically no petroleum, except a small amount accidentally in salt domes, where, along with gas from certain wells, it is used for evaporating brine. It is cased off in the drilling of salt

wells, the brines being found at deeper horizons. Also, a little oil is bailed from drill holes in Shensi, refined by native methods, and used locally. The regions where oil may be developed, judging either from surface indications or from wells, are: Northern Manchuria, Shansi, Shensi, at several points along the Tsche-Kiang-Sia (River), south of the Gobi Desert, at points in Kwangsi, and in the Szechuan and Yunnan salt fields. Of these, Shensi and Szechuan districts are the most promising.

The Standard Oil Company of New York started work under a drilling contract in Shensi some years ago where two Chinese wells were already making a small production. This was soon abandoned for political reasons and unworkable contract terms, also because not much oil was found. A Japanese group is said to have taken over this field recently, in co-operation with Chinese.

Any prediction as to whether China may become an oil-producing country would be highly speculative. It is not at present, and such development as has been done has been unsuccessful.

AMERICAN POSITION IN EUROPEAN AND ASIATIC FIELDS

It is interesting to note how little share we, a nation largely responsible for the creation of the petroleum industry and leaders at all times in the development of its technology, have had in these important foreign operations, and what little chance we have for a future position in them.

The only American company established as a producer in any of the fields discussed is the Standard of New Jersey, operating through its local organization, Romano-Americana, in Rumania. It may be true that American oil capital will take a certain interest with the Turkish Petroleum Company (subsidiary of Anglo-Persian), in the development of Mesopotamia, under terms which considerably favor the British company, and again, according to gossip, it may also be that an American interest is to be permitted to drill a certain amount of acreage in the Dutch East Indies. Standard of New York has been established in the Orient for many years, but its activities hitherto have been confined to the marketing of kerosene and small amounts of other petroleum products, and it has not succeeded in entering into oriental production. No other

American concern, so far as the writer has learned, has succeeded in acquiring and holding any oil land in the countries discussed.

What are the reasons for this? Two main ones occur to the writer:

1. American capital has had plenty to occupy its attention in its own country through a long period of extraordinary prosperity and rapidly growing national wealth. It has, therefore, become impatient at delayed profits, and shrinks from risk to which it is unaccustomed and which does not exist at home. Moreover, America has so isolated itself for half a century that it has become only vaguely familiar with foreign developments. British capital, which is patient with delays and seeks, and is familiar through long experience with, every variety of foreign investment, has become established in many of the fields discussed before Americans could inform themselves and decide whether or not to begin negotiations.

2. American foreign business lacks effective government support. It has been the general aim of our Department of State in the past to protect life rather than property. The policy of isolation advocated by Washington has never been fully abandoned. Though the attitude of our government in the matter of foreign relations has been gradually changing of late years, the change is probably coming too late to help us establish any commanding position in foreign oil fields except in North and South America. Even in the latter country our English friends are strong competitors. At best our government is not so constituted that it can maintain an institution of the nature of the British Foreign Office, with its uninterrupted performance under skilled and experienced guidance, with its vast volume of constantly accumulating facts, assembled by trained men and always available to those seriously contemplating foreign ventures, and with its eternal vigilance in the fostering of British trade and industries in foreign places, and the protection of them with gunboats and armies, if need be.

Reviewing briefly the great producing and prospective oil regions discussed above, recent events are as follows:

Dismissing Russia, which is, for the time being, shunned by all prudent outside capital, and excepting Japan, which is inhospitable to foreign capital and prefers to keep its industries in Japanese

hands, Great Britain is firmly established in all of the other countries above discussed. It dominates in India, of course, but to almost an equivalent degree in Persia and Mesopotamia, divides about equally with the Netherlands the development and operation of the Dutch Indies oil districts, is firmly established in the promising fields of Bulgaria, and, according to press despatches just now arriving, also in those of Albania.

During the same period in which Great Britain has accomplished all of this except its position in India, the history of American efforts has been as follows:

1. Two American companies have attempted to establish themselves in North Persia. A number of years before the war a concession to Russian interests covered the five northern states of Persia. This was eventually taken over by Americans, but they soon found that they were bottled up in the matter of transportation, and in need of political support, so were constrained to seek a combination with the Anglo-Persian Company. The original concession, however, contained a clause requiring the indorsement of the Persian Parliament before there could be any transfer of the concession, or association by the concessionaires with any other persons or companies. The Persian government declared the concession void. Another large American company later apparently succeeded in securing a favorable concession covering the same territory, but finding itself similarly situated, has since withdrawn, more or less concurrently with a recent announcement by the British government that it would not dispose of any of its controlling shares in the Anglo-Persian Company.

2. The Rumanian government, during the latter part of 1924, enacted a drastic mining law, which, as the writer understands, nationalizes minerals beneath the surface and requires, among other things, that oil companies immediately place themselves under Rumanian control and management, and that within ten years from the date of the act 55 per cent of their stock must be actually owned by Rumanian citizens. Whatever the outcome may be, operation in Rumania by an American company just now appears to be under a handicap and fraught with trouble and hazard.

3. A prominent American company not long ago took over prop-

erties in the Grosny field, but according to recent reports has been unable to continue operations and will withdraw altogether. The same company also negotiated a definite contract, indorsed in Moscow, for the development of northern Saghalien, but Russia has turned this territory over to Japan by treaty, and abrogated the contract.

Three American financial groups, two and three years ago, were attempting to establish themselves in Mesopotamia, one aiming to re-establish Abdul Hamid's titles, the others, to secure concessions directly from existing governments. British interests were in such a strong preferential position that these independent American negotiations have not been successful. Efforts made in Bulgaria and Albania have had a similar outcome.

To sum up, excepting in Rumania, where they were established years ago and are now in jeopardy, American interests have no position in the major European or Asiatic oil fields, unless, in one or possibly two regions, as shareholders or in association with English companies. Great Britain will be in a few years the leading petroleum-producing nation of the world, and will be selling us oil. It has taken to heart the lesson of the Great War, before which its oil resources were inadequate for national defense, and acted upon this lesson with promptness and magnificent efficiency.

DISCUSSION

EDWARD BLOESCH: Another reason why American interests are behind in the European-Asiatic fields is that the European oil companies, especially the Dutch, had geologists working in these territories for years while petroleum geology was ridiculed by most of the American oil men. Naturally the European companies were able on geological advice to corner the choice territory.

THE SUBSURFACE DISTRIBUTION OF THE COMANCHEAN IN WESTERN KANSAS

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ABSTRACT

This paper presents the results of a study of many well logs of western Kansas for the light they throw on the subsurface distribution of the Comanchean strata. In Russell and adjacent counties these rocks appear to approximate 200 feet in thickness, but westward and southwestward the thickness seems to increase, becoming 260 feet thick near Voda in Trego County, 456 feet in the Halliday well in Ford County, and 344 feet in the Garden City well in Finney County.

INTRODUCTION

The surface exposures of the Comanchean of Kansas are confined to two parts of the state, of which one is south central, where the exposures form a narrow belt extending from the vicinity of Medicine Lodge westward to beyond Ashland, the strata coming to the surface along the face of the Tertiary capped escarpment to the north, and the other in central Kansas, centering in the region lying between Salina, McPherson, Hutchinson, and Lyons.[1]

In the southern area the strata consist of the Cheyenne sandstone at the base and the Belvidere formation above. The former is a light-colored quartz sandstone with a maximum thickness in the eastern exposures approximating 100 feet. In the western exposures it seems to be thin or wanting. These sandstones have been deposited by both aqueous and eolian processes. The Belvidere formation is of marine origin and consists of black, thin-laminated, bituminous shales, calcareous clay shales, and shell beds, the formation in its eastern distribution having a thickness approximating 200 feet. Above the Belvidere strata are red sandstones of scattered and limited distribution which have been named the "Reeder formation." These belong to the "Dakota."

In the central part of the state the strata show great variation from place to place. At the base is a considerable but variable

[1] For detail of distribution, see *Kan. Geol. Surv. Bull. 9*, 1924.

thickness of non-fossiliferous black, blue, and gray shales in the upper portion of which are shell beds containing marine fossils. These are overlaid by sandstones which range in thickness from 10 to 50 feet. Where exposed, these sandstones have yellow colors, and at the top there is either an oyster shell bed or the red Mentor fossiliferous sandstone. The protean lithology of the Dakota succeeds above. It is extremely difficult to define a plane of separation between the Mentor sandstone and the overlying Dakota. The greatest thickness appears to be in the region south of Marquette in McPherson County, where there are around 100 feet of these strata.

Comanchean rocks occur to the west on the other side of the Cretaceous and Tertiary near Canyon City, Colorado, in a dark shale and shaly sandstone, containing marine fossils and having a thickness of 50–100 feet, overlaid by a coarse gray sandstone with a thickness of 15–60 feet.[1] As the strata have a lithology and fauna very similar to those of Kansas, it may be assumed that there was continuous distribution between the Colorado and Kansas areas, and these strata should be present in the intervening areas unless removed by the pre-Tertiary erosion, which is known to have occurred as shown by the evidence in southern Kansas.

Summarizing the data, it may be noted that the Comanchean strata of southern Kansas consist mainly of black and limy gray shales containing shell limestones with a thickness ranging from 28 to 200 feet underlaid by light-colored sandstone with a thickness up to 100 feet; in central Kansas of shale at the base with a maximum thickness of 50–60 feet overlaid by sandstone ranging in thickness from 10 to 50 feet; and in eastern Colorado of 50–100 feet of dark shales and shaly sandstone underlaid by sandstone of Cheyenne aspect with a thickness of 15–60 feet. Thus the thickness in southern Kansas should range up to 200–300 feet, in central Kansas around 100 feet, and in eastern Colorado about 100 feet. These strata in Kansas are limited below by the Permian and above by the "Dakota" sandy strata.

The extensive search for prospective oil structures has inevitably led geologists to western Kansas, and considerable geologic work has

[1] T. W. Stanton, "The Morrison Formation and Its Relation to the Comanchean and Dakota Formations," *Jour. Geol.*, Vol. 12 (1904), pp. 657–69.

been done there for many years. The discovery of oil in Russell County has greatly stimulated exploration, and has encouraged extensive drilling on inferred and possible anticlinal and domal structures. Many of the wells have been unwisely placed, but their drilling has yielded considerable information, much of which has unfortunately been lost because the samples were not examined by competent geologists.

Among others, the writers were attracted to the region, and the conclusion was early reached that in most instances the surface structures have essentially no value as indications of subsurface structure. Preliminary to the study of subsurface conditions, the logs of all available wells were obtained, and in many instances samples from wells were studied. Unfortunately from the point of view of the present problem, the samples in all instances, except the Davidson well near Voda, were derived from strata deep down in the Pennsylvanian, the operators appearing to be generally of the opinion that samples from the upper strata have no value.

In pursuance of this work, assistance has been received from very many sources. Particular thanks are due to Mr. B. E. LaDow for the opportunity to study the region, to the Keys Petroleum Company for the privilege of studying the samples from the Davidson well, and to the Amerada Petroleum Corporation for the opportunity to study samples collected from many wells by the scouts of that organization. Unfortunately none of the latter samples came from Comanchean horizons.

Where samples have been available, it has not been difficult to recognize the Comanchean strata. The shell beds may be determined and the lower limit accurately drawn. The upper limit in all cases must be approximated. Reliance upon the logs of drillers renders many errors possible and, as this is the only source of information in most cases, it follows that the statements which follow, in most instances, are but approximations toward accuracy.

SUBSURFACE DISTRIBUTION OF THE COMANCHEAN

Information relating to the subsurface distribution of the Comanchean is extensive and most reliable in Russell and adjacent counties, where the discovery of oil on the Fairport anticline led to

the drilling of many wells, of which some were drilled by companies who appreciate the importance of accurate information. The Comanchean portions of a few of the logs are given on the pages which follow.

In the Munsell well in Sec. 17, T. 12 S., R. 15 W., the top of the Comanchean is placed in the lower part of a brown sandstone whose base is 378 feet from the surface. It is suggested that the basal portion of this sandstone may represent the Mentor. The base of the Comanchean is placed at 571 feet, thus giving to the division a thickness of about 200 feet. It is inferred that these 200 feet represent the Belvidere and that no Cheyenne is present.

In the Oswald well in Sec. 8, T. 12 S., R. 15 W., the beds assigned to the Comanchean extends from 372 to 560 feet, or about 200 feet. The same thickness is found in the Milke well in Sec. 20 of the same township and range, and in the Dodge well in Sec. 29, T. 11 S., R. 15 W. In eastern Russell County, in Sec. 1, T. 14 S., R. 11 W., the Deisroth well has 215 feet of strata which appear to be of Comanchean age. This log shows more black shale than the others noted, but it is probable that some of the blue shale of the other wells is really black. The logs of the Comanchean portion of the wells are as follows:

COMANCHEAN STRATA IN RUSSELL COUNTY WELLS

MUNSELL WELL

	Depth in feet
Brown sandstone	360–78
(Mentor may be lower portion)	
Blue shale	408
Gray limestone	411
Blue shale	412
Sandstone	431
Gray limestone	434
Gray sandy shale	470
Blue sandy shale	493
Brown limestone	497
Blue shale	511
Dark sandstone	513
Iron pyrite	518
Blue shale	551
Gray sandstone	563
Gray limestone	571
Permian Red Beds	

OSWALD WELL

	Depth in feet
Soft red sandstone (Mentor?)	372–480
Soft light sandstone	400
Soft blue shale	430
Soft black shale	520
Soft blue shale	530
Soft light shale	540
Soft light sand	548
Soft light shale	560
Permian Red Beds	

MILKE WELL

Sandstone (Mentor at base?)	407–80
Brown sandy limestone	490
Blue shale	510
Blue sandy shale	530
Blue shale	558
Brown shale	580
White shale	588
Brown sand	600
Blue shale	620
Permian Red Beds	

DEISROTH WELL

White sandstone (Dakota)	270–80
Black shale	300
White sandstone	310
Black shale	325
White sandstone	345
Black shale	365
White sandstone	375
Black shale	395
White shale	420
White sandstone	425
Black shale	455
Red sandstone	465
Black shale	495
Permian Red Beds	

Farther east in Lincoln County is the Amerada Crawford well in Sec. 16, T. 11 S., R. 7 W., where the thickness of strata which appears to be of Comanchean age is about 200 feet. The log of the Crawford well follows:

COMANCHEAN STRATA IN THE CRAWFORD WELL, LINCOLN COUNTY

	Depth in feet
Red sandstone (Mentor at base?)	210–50
Light sandstone	260
Black shale	290
White shale	293
Red sandstone	300
Shale	305
Sandstone	315
Black shale	320
Sandstone	395
Black shale	405
Hard limestone	410
Black shale	446
Permian Red Beds	

In general, the information available suggests that in Russell, Lincoln, and adjacent parts of the neighboring counties the Comanchean is represented by about 200 feet of strata. Not all of this may be of that age, but it is considered that such is the maximum thickness which may be assigned to this division.

Southwest of the Fairport anticline in Sec. 3, T. 16 S., R. 16 W., northeastern Rush County, is the Wallace well, in which there appear to be about 200 feet of Comanchean strata. Farther southwest in central Rush County is the Bison well in Sec. 33, T. 17 S., R. 17 W., the log of which suggests that the Comanchean may have a thickness of nearly 300 feet in this district. The Comanchean of the Bison well appears to be assuming the aspect of the southern Kansas strata. It is inferred that the 95 feet of sandstone at the base represent the Cheyenne and the sandstones and shales above the Belvidere. The Comanchean portion of this log is as follows:

COMANCHEAN STRATA IN THE BISON WELL, RUSH COUNTY

	Depth in feet
Hard red sandstone (Mentor at base?)	285–305
Soft white sandstone	365
Blue shale	368
Soft sandstone	370
Blue shale	388
Sandstone	403
Blue shale	412
Sandstone	421
Black shale	434

	Depth in feet
Sandstone and black shale	464
Conglomerate	478
Black shale	492
Sandstone	587
Permian Red Beds	

A well still farther west is located on the Davidson farm near Voda, Trego County, in Sec. 16, T. 11 S., R. 24 W., and through the kindness of the Keys Petroleum Company samples from this well to a depth of 3,030 feet were studied. The Comanchean is thought, on very strong evidence, to extend from 1,075 to 1,335 feet, giving a thickness of 260 feet. This thickening westward is in harmony with the record of other wells in that direction. The strata from 1,240 to 1,325 feet are thought to represent the Cheyenne sandstone. The log is as follows:

COMANCHEAN STRATA IN THE DAVIDSON WELL, TREGO COUNTY

	Depth in feet
Fine gray sandstone (Dakota)	1,030–75
Blue shale	1,160
Dark shale and gray sandstone	1,175
Dirty gray sandstone	1,195
Dark-blue shale	1,240
White sandstone	1,245
Clayey sandstone	1,300
White sandstone	1,325
Permian Red Beds	

Still farther west and south in Sec. 27, T. 15 S., R. 31 W., in western Gove County is the so-called Plateau well, in which there appears to be 364 feet of Comanchean beds,[1] extending from 1,146 to 1,510 feet, both the Belvidere and Cheyenne being represented. The log of this well is given below:

COMANCHEAN STRATA IN THE PLATEAU WELL, GOVE COUNTY

	Depth in feet
Sandstone (Dakota)	1,110–46
Dark shale	1,385
Sandstone	1,400
Sandstone and shale	1,510
Permian Red Beds	

[1] C. T. Lupton, W. Lee, and L. R. Van Burgh, "Oil Possibilities of Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 6 (1922), p. 74. These authors place the thickness at 400 feet.

Farther south and west in Sec. 2, T. 24 S., R. 23 W., Hodgeman County, is the Whiteside well, of which a very good log appears to have been kept, and according to which the top of the Comanchean is at 210 feet and the base at 390 feet, giving a thickness of 180 feet. The Cheyenne is inferred to extend from 335 to 390 feet. The section in this well is as follows:

COMANCHEAN STRATA IN THE WHITESIDE WELL, HODGEMAN COUNTY

	Depth in Feet
Red sandstone (Dakota)	210
Shale	250
Limestone	265
Dark shale (coal showing)	300
Red rock	315
Shale	335
Sandstone	390
Permian Red Beds	

The next well to the south is the Halliday, in Sec. 7, T. 25 S., R. 23 W. This is 16 miles northeast of Dodge City, in northern Ford County. The log of this well is detailed and seems reliable. It suggests that the Cheyenne sandstone is 191 feet thick and the Belvidere 265 feet, or a total of 456 feet of Comanchean strata. If correct, this is the thickest section of the Comanchean known in Kansas. The thickness of the Belvidere is not excessive, and that of the Cheyenne presents no difficulty as the method and environment of its origin predicate great variation in thickness. The suggested small representation of Comanchean strata is the not far-distant Whiteside well may be due to pre-Dakota erosion or lesser deposition. From the surface downward the log is as follows:

RECORD OF HALLIDAY WELL, FORD COUNTY

	Depth in Feet
Soil	20
Soft limestone	40
Blue shale	80
Red rock	100
Shell limestone	110
Sandstone	130
Dark shale	170

	Depth in feet
Light sandstone	185
Light shale	195
Red rock	225
Light sandstone	240
Dark shale	260
Red rock (base, Dakota?)	275
Light limestone	290
Light sandstone	350
Hard limestone	360
Dark shale	363
Light limestone	384
Dark shale	400
Light limestone	415
Shale	450
Light sandstone	470
Dark shale	515
Light sandstone	530
Dark shale	540
Heavy sandstone	731
Permian Red Beds	

The next well to the south is in T. 30 S., R. 23 W., 1 mile west of Mineola in Ford County. The log of this well shows 190 feet of strata which are referred to the Comanchean. As the well is not far from the Bluff Creek Canyon, it is probable that the thickness is approximately correct. No Cheyenne appears to be present.

The most western well in Kansas of which a reliable log has been seen is that of Garden City in Sec. 30, T. 21 S., R. 30 W., Finney County. The log of this well shows 344 feet of strata which appear to belong to the Comanchean. The Belvidere formation is inferred to extend from 880 to 1,135 feet, and the Cheyenne from that depth to 1,224 feet. The Comanchean strata are as follows:

COMANCHEAN STRATA IN THE GARDEN CITY WELL, FINNEY COUNTY

	Depth in Feet
Red rock (base, Dakota?)	874–80
Black shale	956
Shale	1,030
Sandstone	1,055
Shale	1,062

	Depth in feet
Sandstone	1,080
Shale	1,089
Black shale	1,092
Limestone	1,099
Sandstone	1,106
Shale	1,135
Sandstone	1,151
Shale	1,155
Permian Red Beds	

Summary.—It seems probable that in Russell and adjacent counties the thickness of the Comanchean approximates 200 feet, and the thickness appears to increase westward and southward, becoming 260 feet in the Davidson well near Voda in Trego County, 456 feet in the Halliday well in Ford County, and 344 feet in the Garden City well in Finney County. With progress southward the strata shown in the well logs assume the aspect of the Comanchean of the southern exposures. It seems probable that the center of the basin of deposition lay in the general region of the thickest deposits. The strata assigned to the Cheyenne show an erratic distribution in harmony with what seems to have been the method and environment of their deposition.

POSSIBILITY OF COMMERCIAL OIL IN THE COMANCHEAN AND HIGHER STRATA OF THIS REGION

This article would not be complete were not this factor considered. Some of the Comanchean and higher horizons are ideal for the accumulation of oil, and there are no doubt many places where the structural conditions are favorable. However, so far as Kansas is concerned, it is considered improbable that these strata will contain commercial oil to any large degree. This conclusion is based on the extensive underground water circulation, the water in most instances being fresh; and the fact that of the many wells which have penetrated these strata under favorable structural conditions not one has yielded commercial oil, newspaper reports to the contrary notwithstanding.

GEOLOGICAL NOTES

PRE-CAMBRIAN RHYOLITE DISCOVERED IN WELL IN NORTHWESTERN ARKANSAS[1]

Rhyolite has been discovered recently in a deep well in the northern part of the Boston Mountains, in northwestern Arkansas. It was encountered underneath probable Cambrian rocks and is doubtless of pre-Cambrian age like the granite that has been found in numerous wells in Missouri, Nebraska, Kansas, and Oklahoma. This announcement gives, so far as the writers know, the first recorded discovery of igneous rocks of this age in Arkansas. Also the occurrence is one of the few localities in the Ozark region and adjoining parts of the lower Mississippi Valley where volcanic rocks of pre-Cambrian age are known. The well was drilled by W. H. Brener in search of oil, in Sec. 13, T. 15 N., R. 26 W., Madison County. It is 1–2 miles south of the Eureka Springs quadrangle whose geology is described in the Eureka Springs–Harrison folio (No. 202). The rhyolite was encountered at a depth of 2,286 feet and the last cuttings received at the Geological Survey showed that the well had been bored 34 feet into it. The rock is composed of phenocrysts of plagioclase and orthoclase in a very fine-grained ground-mass of feldspar and quartz. The rock would be described as a porphyritic rhyolite and the structure indicates that it may be a volcanic flow or an intrusive of limited size that crystallized at shallow or intermediate depths. The type of alteration that the rhyolite has undergone is similar to that observed in pre-Cambrian granites from Kansas, Oklahoma and the Panhandle region of Texas.

The log and cuttings which have been supplied by Mr. Brener indicate that the following formations were penetrated by the well:

	Depth (Ft.)	Thickness (Ft.)
Hale formation (Pennsylvanian) and Pitkin limestone (Mississippian)	8 – 103½	95½
Fayetteville shale (Mississippian)	103½ – 262	158½
Batesville sandstone (Mississippian)	262 – 369	107
Boone limestone (Mississippian)	369 – 626	257
Chattanooga shale (Devonian?)	626 – 654	28
St. Clair limestone (Silurian) or Fernvale limestone (Ordovician)	654 – 670	16
Jasper and Joachim limestones (Ordovician)	670 – 732	62
St. Peter sandstone (Ordovician)	732 – 948	216
Sandstone and limestone of Ordovician and Cambrian age	948 – 2,286	1,338
Rhyolite of pre-Cambrian age	2,286 – 2,320	34+

HUGH D. MISER
CLARENCE S. ROSS

[1] Published by permission of the Director of the U. S. Geological Survey.

NAMES OF PRODUCING SANDS IN THE SMACKOVER, ARKANSAS, FIELD

In an attempt to remedy a general confusion regarding the identity of the different producing sands in the Smackover district, the Shreveport Geological Society appointed a committee last June, with the writer as chairman, to study the situation in order to standardize one name for each sand.

The production comes from four major and several minor sands of Upper Cretaceous age. These sands are contained in 670 feet of sediments composed of sand, sandstone, sandy shale, and clay, which grade laterally in short distances into one another, each having similar lithologic characteristics. The section in the Smackover field is different from sections of the same age in surrounding fields, and several sands have produced for the first time here. These confusing factors tend to make it difficult to distinguish different sands in different parts of the field. The four producing sands in the Smackover district have been named Nacatoch, Meakin, Graves, and Blossom.

The Nacatoch is found from 1,925 to 2,150 feet beneath the surface and is productive from 1,800 to 1,890 feet below sea-level. The producing sands average about 25 feet in thickness, and are contained in a vertical thickness of 165 feet. The Nacatoch is also known as the "shallow sand," or "first sand." It is productive of oil, or gas, practically over the entire district, and is one of the two main producing sands in the field. The largest well had an initial production of 25,000 barrels of oil daily. The gravity of the oil averages 20° A.P.I.

The Meakin sand is the second producing formation encountered. It is 320 feet below the top of the Nacatoch and is found productive at depths from 2,230 to 2,360 feet, or 2,100 to 2,180 feet below sea-level. It has an average thickness of 55 feet. It is productive of oil and gas in the northwestern part of the field, and of dry gas, or gas and a small show of oil, in the eastern part of the field. The oil wells have an average initial production of 200 barrels of oil, the gravity of which averages 25° A.P.I. The gas wells have an average initial production of 30,000,000 cubic feet of gas and a rock pressure of 900 pounds per square inch. This producing sand has already been named and described by the writer.[1] It is also known as the "Louann," "2,200-foot," "2,300-foot," and "light oil" sand, and in the eastern part of the field it has been called the "Primm gas zone."

The third producing sand has been named by this committee, the Graves sand, from the name of the farm on which was drilled the first well that produced from this sand. This well was drilled by the Lion Oil and Refining Company on the Graves lease, which is the southeast quarter of the southwest quarter of Sec. 3, T. 16 S., R. 15 W. The top of the Graves sand is 460 feet below the top of the Nacatoch and is found productive from 2,340 to 2,500 feet below the sur-

[1] H. G. Schneider, "Smackover Oil Field, Ouachita and Union Counties, Arkansas," *Trans. A. I. M. and M. E.*, Vol. 70 (1924), p. 1084.

face, or 2,240 to 2,300 feet below sea-level. It has an average thickness of 35 feet. This sand, together with the Nacatoch, produces most of the oil in the field. The average initial production is 2,000 barrels of oil per well daily, though several wells were completed that had an initial production of 15,000 to 70,000 barrels of oil daily. The gravity of the oil averages 21° A.P.I. The formation is productive only in the eastern part of the field. The field name for the sand is the "2,400-foot" sand.

The Blossom sand is found about 600 feet below the top of the Nacatoch, and 2,550 to 2,660 feet below the surface. The average depth below sea-level of the top of the sand is 2,450 feet. It has an average thickness of 20 feet. About twelve wells have been completed in the western part of the field. These wells have an average initial production of 50 barrels of oil, of which the gravity averages 19° A.P.I. In the eastern part of the field several recent completions have shown that both oil and gas are found in the sand. The oil wells have an initial production of 300 to 3,000 barrels daily and the gas wells have an initial production of 40,000,000 cubic feet of gas daily and a rock pressure of 1,100 pounds per square inch. The gravity of the oil in the eastern part of the field averages 24° A.P.I. This sand was also recognized at Smackover by the writer in the same paper[1] in which the Meakin sand was named. Other names for this sand are "2,600-foot" and "deep sand."

Between the Graves and the Blossom sands and the formations included in the seventy feet just beneath the Blossom, several stray sands have been found that have produced small quantities of oil in only one or two wells. Since these sands, up to the present time, are unimportant as oil-producing formations, no attempt has been made to name them.

H. G. SCHNEIDER

SHREVEPORT, LOUISIANA

[1] *Op. cit.*, p. 1084.

REVIEWS AND NEW PUBLICATIONS

"Paraffin Dirt," Its Nature, Origin, Mode of Occurrence, and Significance as an Indication of Petroleum. By H. B. MILNER, with Report of Chemical Investigations by A. WOLF. *Mining Magazine* (London), February, 1925, pp. 73–85.

This paper gives a description of "paraffin dirt," and the conditions under which it occurs, based on a review of the literature, on a hasty visit to some of the less well developed occurrences, and on discussions with American geologists, a summary of the opinions of American geologists in regard to its origin and significance, the results of a petrologic examination of it by Milner and of a chemical investigation of it by Wolf, and Milner's conclusions in regard to its nature, origin, and significance as an indication of petroleum.

The petrologic examination included microscopic examination of thin sections and of crushed material, and heavy-light mineral separation and comparison with other Gulf Coast material. The conclusions are that "paraffin dirt" is a true soil in all respects, and contains no fundamental structure or mineral composition differentiating it from other soils, that its peculiar properties have developed subsequent to its formation as an ordinary soil, and that it is a colloidal system characterized by an abnormal amount of colloidal organic matter.

The chemical investigation consisted of determination of hygroscopic moisture and dried ignition loss, extraction with petroleum spirit, benzol, and absolute alcohol (total amount extraction = 1.61 per cent), determination of the saponification values of the extracts, separation of each extract into unsaponifiable and saponifiable matter soluble in hot alkalies, a Lieberman-Storch test for resin, and determinations of the iodine values of the saponifiable and unsaponfiable components. Wolf's conclusions are that the "paraffin dirt" is free from paraffin hydrocarbons, napthene hydrocarbons, resins, wax alcohols, and any chemical compounds which one would expect to be associated with, to give rise to, or to result from the chemical decomposition or oxidation of crude petroleum, that it appears to contain only those constituents normal to most soils, that it is abnormal in its high content of organic matter, and that its curious elasticity appears to be intimately associated with certain colloidal characteristics, which may be related to the high content of organic matter.

As the result of his own petrologic studies and Wolf's chemical investigation, Milner concludes that the following points have been clearly demonstrated: (1) "Paraffin dirt" is not a definite chemical compound as has been suggested by some observers. (2) It is not paraffinaceous. (3) It is not a residual product of inspissated petroleum and cannot be classed with the solid bituminous indications of that fluid. (4) Petrologically, it is an argillaceous soil whose detrital

constituents are closely related to the recent deposits of the Gulf Coastal Plain, though it contains an abnormal amount of organic matter. (5) The peculiar rubbery, elastic property of "paraffin dirt" is due to imperfect adsorptive (gas-fluid) saturation of the very considerable amount of colloidal organic matter in this soil and the consequent unstable physical state that prevails until complete saturation. (6) The formation of this peculiar state in the soil occurs only under certain conditions dependent somehow on the nature and concentration of the impregnating fluids, on the presence of meteoric water, and indirectly on microbiologic influences. If gas impregnation is an important factor, the most important gas is methane, but it is unnecessary to postulate ascending petroleum gas, as there is abundant evidence of gas generation within the soil. Any microbiologic activity would be of an anerobic character and would be controlled largely by the fluids present. It is possible that not sufficient importance has been attached to the action of specific bacteria working on localized types of vegetation.

Milner's final conclusions are that "paraffin dirt" is no reliable index of petroleum; that its occurrence is largely a matter of chance, given a favorable environment where physiography, climate, and vegetation are mutually conducive to its formation, that the association of "paraffin dirt" with the salt domes and oil fields of the Gulf Coast is apparent rather than real, and that when the vast tracts of swamp, forest, and prairie away from them are thoroughly explored the occurrence of "paraffin dirt" will be found to be much more widespread. He concludes with a plea of the urgent necessity for co-operative research between bacteriologists, soil chemists, and geologists on such problems.

This paper gives British geologists a fair summary of the knowledge of "paraffin dirt" as expressed by the American literature, not all of which should be taken at its face value. The paper is important for the emphasis which it places on the colloidal organic nature of the "paraffin dirt" but otherwise does not advance knowledge of it. It is unfortunate that Milner did not have the opportunity to make a closer study of one of the better "paraffin dirt" occurrences, and of the geology of its occurrence in the Gulf Coast of Texas and Louisiana, and to investigate the organic matter more closely, for it seems evident to the reviewer that Milner did not quite learn to recognize "paraffin dirt" or the character of its occurrence. If he had carried field and laboratory examination further, he would probably have come to different conclusions in regard to its nature and origin. The description of it in this paper is not definite enough to serve as a reliable guide to its identification by anyone not familiar with it.

The conclusion that "paraffin dirt" is an argillaceous soil normal to the region but possessing an abnormal amount of colloidal organic matter, that it is not paraffinaceous and is not the residual product of inspissated petroleum, and that it owes its peculiar rubbery character to its nature as a colloidal, probably chiefly organic, system, cannot be assailed. The explanation of the physical cause of the rubbery character of the "paraffin dirt" does not convince the reviewer but he is not physicist enough to be able to dispute it.

The conclusions that "paraffin dirt" is not a definite chemical compound and in regard to its origin are open to challenge. Strong evidence is now available to show that this material is an argillaceous soil permeated by a definite chemical substance or group of substances which is organic in origin, formed by bacteria living in part at least on methane and oxygen. From quartered samples, a water extract can be obtained from the one half which amounts to 35 to 50 per cent of the dried ignition loss in the other half. The extract evaporated to dryness is a dark red, brittle substance with a sickish sweet smell vaguely like that of licorice and with a specific gravity of 1.11 and a dried ignition loss of 95 per cent. The ignitable material of five well-dried samples carefully selected to be as free as possible of roots, etc., had specific gravities of 1.09±0.06. C. D. Lowry, chemist, reports tentatively in a letter that "paraffin dirt" seems to be some sort of polysaccharide, seemingly containing pentoses, and that Professor Becking, bacteriologist of Stanford, reports that it is probably due to bacteria living on the methane. E. C. Jeffrey, botanist, reports that it is a mass of low-grade organisms living in a common gelatinous matrix. The connection of "paraffin dirt" with gas seeps in which methane is the main gas seems definite. The work of Soehngen has shown that there are soil bacteria which oxidize methane in the presence of oxygen, with the liberation of carbon dioxide. As the permeation of the soil by the "paraffin dirt" is greatest within 3 inches of the surface and rapidly decreases downward so that at a depth of 2 feet the "paraffin dirt" is found only in cracks, it is very suggestive that some such bacteria are the cause of the "paraffin dirt."

The statement that "paraffin dirt" is not a reliable index of petroleum is strictly correct, but the reviewer knows no reliable index of petroleum except a successfully completed producing well. The association of "paraffin dirt" with (methane) gas seeps is definite and the size of the "paraffin dirt" bed is directly proportional to the size of the gas seep. The significance of "paraffin dirt" is, therefore, the same as that of a gas seep. Milner seems to think that the methane can be accounted for by the generation of marsh gas in the zone of the soil, but it seems very doubtful whether the amount of marsh gas generated in the zone of the soil can be sufficient to maintain the constant, localized ebullition of gas that characterizes all the well defined "paraffin dirt" beds. It is certainly the experience of Gulf Coast geologists that there is a vast difference between the sporadic, shifting bubbling of marsh gas in swampy land or marshes and the regular localized bubbling of gas that characterizes seeps of gas from subsurface beds. The relation of the known "paraffin dirt" beds to seeps of gas coming from below the surficial zone seems definite. Apparently impressed by the vastness of the Texas-Louisiana coastal prairies, Milner thinks that with the increasing exploration of them, "paraffin dirt" will be found to be much more widespread and not to be restricted to association with salt domes and oil fields, but he is apparently unaware that in addition to the 25 odd professional geologists and perhaps slightly greater number of oil scouts, there are a horde of amateur oil men who themselves roam the prairies, who listen for and follow

up the slightest report of any unusual soil, seep, incrustation, etc., and then show any suspicious occurrence to as many geologists as they can get to look at it. Although it is, of course, probable that some "paraffin dirt" beds have not been discovered, it seems highly improbable that "paraffin dirt" beds occur undiscovered in number and size comparable to those already known.

In the area of the Mississippi delta, gas seems to be fairly widespread, is rather commonly present under considerable pressure in relatively shallow sands and escapes through numerous well-defined gas seeps. A zone that runs through Sabinetown on a line roughly parallel to the outcrop of formations is characterized by large gas seeps and much gas in wells. In both of these areas, most of the gas has not been proved to be associated with petroleum; and the gas seeps and the "paraffin dirt" beds which commonly accompany them are very unreliable indices of petroleum. In the area of the coastal prairie from Lafayette, Louisiana, to Markham, Texas, gas seeps and "paraffin dirt," with a few exceptions for gas seeps, are closely associated with the oil fields, and in that area gas seeps and "paraffin dirt" are fairly reliable indices of petroleum. If "paraffin dirt" occurs elsewhere, similar relations will probably hold.

DONALD C. BARTON

The Bottom Deposits of Lake Ontario. By E. M. KINDLE, *Trans. Royal Soc. Canada*, 3d Ser., Vol. 19 (1925), pp. 17–92, Figs. 1–4, plates 1–3.

This paper is one of the most important dealing with lake deposits which has appeared for a long time. It is particularly important to geology in that it is a study of sediments now in process of formation rather than a study of those which have become a part of the geologic column. It is a study of historical geology and stratigraphy in the making rather than in their completion.

The study of the bottom deposits of Lake Ontario was limited to "certain selected areas which it was believed would give a clear idea of bottom conditions prevailing throughout the lake" and in addition traverses were made on three lines entirely across the lake, two near the southwest end and one near the northeast end. Three areas were selected, one near Hamilton on the extreme southwest and the other two on the north side, one near Toronto and the other in Wellington Bay near the northeast end.

As Lake Ontario is one of the large fresh-water lakes of the world, it is probable that the results of this study are applicable to other large lakes of the same general latitude.

The methods of study and the various general features of Lake Ontario—its shape, depths, temperatures of the water, materials of the lake shore, etc.—are described in detail. The factors responsible for the distribution of sediments are discussed and some interesting and important data are presented of which perhaps the most striking is that relating to the depth of wave and current action, one instance which is given relating to the tug "Walker" sunk in 65 feet

of water. At this depth the waves were strong enough to pound great holes in the hull and to wash 75 tons of coal out of the tug. The depths of wave and current action also are shown by the fact that there are places over the southern third of the lake which have hard rock bottom in water 300 to 450 feet deep. If no deposition occurs at such depths in lakes it is obvious that similar conditions should extend to greater depths in the open ocean.

Some interesting data are given relating to the filling of bays and lagoons, but the most valuable part of the paper deals with the bottom deposits. Near Hamilton the bottom deposits may be grouped in three zones which outward from the bar at this place consist of a belt of clean sand from ½ to 1½ miles wide, a belt of sandy mud or muddy sand about 2 miles wide and beyond that dull-yellow to black mud. Along the south shore of the lake in this region there is an extensive area about 2 miles wide and extending to a depth of about 45 or 50 feet of which the bottom is composed of bare rock. About Toronto there is a somewhat erratic distribution of the shallow water sediments. A great tongue of gravel extending from the northeast is bordered both on the inner and outer sides by sand, the gravel extending to depths exceeding 70 feet, and a tongue of mud bordered on each side by sand extends outward from the mouth of Humber River. The muds of the deeper waters begin in depths of about 200 feet at distances of 4½ to 8 miles from the shore. In Wellington Bay nearly all of the bottom between 60 and 150 feet appears to have rock bottom on which a thin veneer of unconsolidated materials may be found in places. In deeper water beyond this rock bottom the deposits are muddy sands which ultimately give place to muds. Shoreward from the bare rock bottom there is much variation of the bottom materials which consist in some places of sand, in others of gravel, and in still others of mud. There are places where bare rock bottom extends to the shore. That this bare rock bottom is bordered both on its inner and outer sides by sediments is noteworthy.

The deposits of the deep water from 200 to 700 feet or more consist of fine mud of a jell-like consistency. The colors range from buff-gray to blacks which in some instances are in alternating bands. Remains of molluscan life are essentially absent in these deeper deposits. Small shrimps are present in the shallower portions while the deeper muds, below about 250 feet, have minute hair-like worms as the only representative of animal life. Diatoms seem to be present in considerable numbers and form an important part of the sediments.

The great bulk of the animal life of Lake Ontario lives within 25 feet of the surface and essentially all the molluscan life is found within 50 feet of the surface. At depths of 50–100 feet live a few mollusks and there are found dead shells of others. Below 100 feet there is little bottom animal life other than four species of one genus of mollusk and the one species of shrimp and the small hair-like worms already mentioned. This variation in the organic content of sediments of the same time relation should be of great interest to the paleontologist and stratigrapher.

The plant life is also confined to the upper 200 feet of the bottom and below 200 feet the lake seems to be barren of plant life.

The only improvement which the reviewer can suggest for this paper would have been the preparation of a summary of the more striking results. This would have enabled a busy reader to grasp its important lessons without the necessity of reading the entire paper. As it is, the results of the study will fail to be appreciated by many students. However, no geologist who is interested in the questions of sediments and stratigraphy can afford to miss reading any part of the paper. It is to be regretted that extensive detailed work of a similar character upon selected portions of the ocean bottom cannot be brought to materialization.

W. H. TWENHOFEL

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